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CHEMISTRY.

COMPRISING HIS

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BY JUSTUS LIEBIG, M.D., PH.D., F.R.S.

PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF GIESSEN.

"It is not too much to say, that the publication of Professor Liebig's Organic Chemistry of Agriculture constitutes an era of great importance in the history of Agricultural Science. *Its acceptance as a standard is unavoidable; for following closely in the straight path of inductive Philosophy, the conclusions which are drawn from its data are incontrovertible.* We can truly say, that we have never risen from the perusal of a book with a more thorough conviction of the profound knowledge, extensive reading, and practical research of its author, and of the invincible power and importance of its reasonings and conclusions, than we have gained from the present volume."—*Silliman's Journal.*

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CHEMISTRY

IN ITS APPLICATION TO

AGRICULTURE AND PHYSIOLOGY.

BY JUSTUS LIEBIG, M.D., PH.D. F.R.S., M.R.I.A.,

PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF GIESSEN; KNIGHT OF THE HESSIAN ORDER, AND OF
THE IMPERIAL ORDER OF SAINT ANN; MEMBER OF THE ROYAL ACADEMY OF SCIENCES OF
STOCKHOLM; CORRESPONDING MEMBER OF THE ROYAL ACADEMIES OF SCIENCES OF
BERLIN AND MUNICH; OF THE IMPERIAL ACADEMY OF ST. PETERSBURGH; OF
THE ROYAL INSTITUTION OF AMSTERDAM, ETC. ETC.

EDITED FROM THE MANUSCRIPT OF THE AUTHOR

BY LYON PLAYFAIR, PH.D.

FROM THE LAST LONDON EDITION, MUCH IMPROVED.

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TO

THE BRITISH ASSOCIATION

FOR

THE ADVANCEMENT OF SCIENCE.

One of the most remarkable features of modern times is the combination of large numbers of individuals representing the whole intelligence of nations, for the express purpose of advancing science by their united efforts, of learning its progress, and of communicating new discoveries. The formation of such associations is, in itself, an evidence that they were needed.

It is not every one who is called by his situation in life to assist in extending the bounds of science; but all mankind have a claim to the blessings and benefits which accrue from its earnest cultivation. The foundation of scientific institutions is an acknowledgment of these benefits, and this acknowledgment proceeding from whole nations may be considered as the triumph of mind over empiricism.

Innumerable are the aids afforded to the means of life, to manufactures and to commerce, by the truths which assiduous and active inquirers have discovered and rendered capable of practical application. But it is not the mere practical utility of these truths which is of importance. Their influence upon mental culture is most beneficial; and the new views acquired by the knowledge of them enable the mind to recognise, in the phenomena of nature, proofs of an Infinite Wisdom, for the unfathomable profundity of which, language has no expression.

At one of the meetings of the chemical section of the "British Association for the Advancement of Science," the honourable task of preparing a Report upon the state of Organic Chemistry was imposed upon me. In the present work I present the Association with a part of this report.

I have endeavoured to develope, in a manner correspondent to the present state of science, the fundamental principles of Chemistry in general, and the laws of Organic Chemistry in particular, in their application to Agriculture and Physiology; to the causes of fermentation, decay, and putrefaction; to the vinous and acetous fermentations, and to nitrification. The conversion of woody fibre into wood and mineral coal, the nature of poisons, contagions, and miasms, and the causes of their action on the living organism, have been elucidated in their chemical relations.

I shall be happy if I succeed in attracting the attention of men of science to subjects which so well merit to engage their talents and energies. Perfect Agriculture is the true foundation of all trade and industry—it is the foundation of the riches of states. But a rational system of Agriculture cannot be formed without the application of scientific principles; for such a system must be based on an exact acquaintance with the means of nutrition of vegetables, and with the influence of soils and action of manure upon them. This knowledge we must seek from chemistry, which teaches the mode of investigating the compostion and of studying the characters of the different substances from which plants derive their nourishment.

The chemical forces play a part in all the processes of the living animal organism; and a number of transformations and changes in the living body are exclusively dependent on their influence. The diseases incident to the period of growth of man, contagion and contagious matters, have their analogues in many chemical processes. The investigation of the chemical connection subsisting between those actions proceeding in the living body, and the transformations presented by chemical compounds, has also been a subject of my inquiries. A perfect exhaustion of this subject, so highly important to medicine, cannot be expected without the co-operation of physiologists. Hence I have merely brought forward the purely chemical part of the inquiry, and hope to attract attention to the subject.

Since the time of the immortal author of the "Agricultural Chemistry," no chemist has occupied himself in studying the applications of chemical principles to the growth of vegetables, and to organic processes. I have endeavoured to follow the path marked out by Sir Humphry Davy, who based his conclusions only on that which was capable of inquiry and proof. This is the path of true philosophical inquiry, which promises to lead us to truth—the proper object of our research.

In presenting this report to the British Association I feel myself bound to convey my sincere thanks to Dr. Lyon Plairfair, of St. Andrew's, for the active assistance which has been afforded me in its preparation by that intelligent young chemist, during his residence in Giessen. I cannot suppress the wish that he may succeed in being as useful, by his profound and well grounded knowledge of chemistry, as his talents promise.

JUSTUS LIEBIG.

Giessen, September 1, 1852.

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IRREGULAR PAGINATION

EDITOR'S PREFACE.

THE former edition of this work was prepared in the form of a report on the present state of Organic Chemistry. The state of a science such as this could not be exhibited by a systematic treatise on organic compounds, but by showing that the science was so far advanced as to be useful in its practical applications.

The work was written by a Chemist, and addressed to Chemists. The author did not flatter himself that his opinions would be so eagerly embraced by agriculturists, as circumstances have shown to be the case. Hence his language and style were less adapted for them than for those who are conversant with the abstract details of chemical science. But the eager reception of the work by agriculturists has shown that they possess an ardent desire to profit by the aids offered to them by Chemistry. It, therefore, became necessary to adapt the work for those who have not had an opportunity of making that science a peculiar object of study.

The Editor has endeavoured to effect this change. In doing so, it was necessary to retain the original character of the work; hence those alterations only have been made which are calculated to render the work more generally useful. It must be remembered that the object of the author was not to write a "System of Agricultural Chemistry," but to furnish a "Treatise on the Chemistry of Agriculture." It is to be hoped that those who are acquainted with the general doctrines of Chemistry will find no difficulty in comprehending any of the principles here developed.

The author has enriched the present edition with many valuable additions; allusion may be particularly made to the practical illustration of his principles furnished in the Supplementary Chapter on Soils. The analyses of soils contained in that chapter will serve to point out the culpable negligence exhibited in the examination of English soils. Even in the analyses of professional chemists, published in detail, and with every affectation of accuracy, the estimation of the most important ingredients is neglected. How rarely do we find phosphoric acid among the products of their analyses? potash and soda would appear to be absent from all soils in the British territories! Yet these are invariable constituents of fertile soils, and are conditions indispensable to their fertility.

Primrose, November 22, 1852.

ORGANIC CHEMISTRY

IN ITS APPLICATION TO

VEGETABLE PHYSIOLOGY AND AGRICULTURE.

THE object of Chemistry is to examine into the composition of the numerous modifications of matter which occur in the organic and inorganic kingdoms of nature, and to investigate the laws by which the combination and decomposition of their parts is effected.

Although material substances assume a vast variety of forms, yet chemists have not been able to detect more than fifty-five bodies which are simple, or contain only one kind of matter, and from these all other substances are produced. They are considered simple only because it has not been proved that they consist of two or more parts. The greater number of the elements occur in the inorganic kingdom. Four only are found in organic matter.

But it is evident that this limit to their number must render it more difficult to ascertain the precise circumstances under which their union is effected, and the laws which regulate their combinations. Hence chemists have only lately turned their attention to the study of the nature of bodies generated by organized beings. A few years have, however, sufficed to throw much light upon this interesting department of science, and numerous facts have been discovered which cannot fail to be of importance in their practical applications.

The peculiar object of organic chemistry is to discover the chemical conditions essential to the life and perfect development of animals and vegetables, and generally to investigate all those processes of organic nature which are due to the operation of chemical laws. Now, the continued existence of all living beings is dependent on the reception by them of certain substances, which are applied to the nutrition of their frame. An inquiry, therefore, into the conditions on which the life and growth of living beings depend, involves the study of those substances which serve them as nutriment, as well as the investigation of the sources whence these substances are derived, and the changes which they undergo in the process of assimilation.

A beautiful connection subsists between the organic and inorganic kingdoms of nature. Inorganic matter affords food to plants, and they, on the other hand, yield the means of subsistence to animals. The conditions necessary for animal and vegetable nutrition are essentially different. An animal requires for its development, and for the sustenance of its vital functions, a certain class of substances which can only be generated by organic beings possessed of life. Although many animals are entirely carnivorous, yet their primary nutriment must be derived from plants; for the animals upon which they subsist receive their nourishment from vegetable matter. But plants find new nutritive material only in inorganic substances. Hence one great end of vegetable life is to generate matter adapted for the nutrition of animals out of inorganic substances, which are not fitted for this purpose. Now the purport of this work is, to elucidate the chemical processes engaged in the nutrition of vegetables.

The first part of it will be devoted to the examination of the matters which supply the nutriment of plants, and of the changes which these matters undergo in the living organism. The chemical compounds which afford to plants their principal constituents, viz., carbon and nitrogen, will here come under consideration, as well as the relations in which the vital functions of vegetables stand to those of the animal economy and to other phenomena of nature.

The second part of the work will treat of the chemical processes which effect the complete destruction of plants and animals after death, such as the peculiar modes of decomposition, usually described as *fermentation*, *putrefaction*, and *decay*; and in this part the changes which organic substances undergo in their conversion into inorganic compounds, as well as the causes which determine these changes, will become matter of inquiry.

IRREGULAR PAGINATION

PART I.

OF THE CHEMICAL PROCESSES IN THE NUTRITION OF VEGETABLES.

CHAPTER I.

OF THE CONSTITUENT ELEMENTS OF PLANTS.

THE ultimate constituents of plants are those which form organic matter in general, namely, Carbon, Hydrogen, Nitrogen, and Oxygen. These elements are always present in plants, and produce by their union the various proximate principles of which they consist. It is, therefore, necessary to be acquainted with their individual characters, for it is only by a correct appreciation of these that we are enabled to explain the functions which they perform in the vegetable organization.

Carbon is an elementary substance, endowed with a considerable range of affinity. With oxygen it unites in two proportions, forming the gaseous compounds known under the names of carbonic acid and carbonic oxide. The former of these is emitted in immense quantities from many volcanoes and mineral springs, and is a product of the combustion and decay of organic matter. It is subject to be decomposed by various agencies, and its elements then arrange themselves into new combinations. Carbon is familiarly known as *charcoal,* but in this state it is mixed with several earthy bodies; in a state of absolute purity it constitutes the diamond.

Hydrogen is a very important constituent of vegetable matter. It possesses a special affinity for oxygen, with which it unites and forms water. The whole of the phenomena of decay depend upon the exercise of this affinity, and many of the processes engaged in the nutrition of plants originate in the attempt to gratify it. Hydrogen, when in the state of a gas, is very combustible, and the lightest body known; but it is never found in nature in an isolated condition. Water is the most common combination in which it is presented; and it may be removed by various processes from the oxygen, with which it is united in this body.

Nitrogen is quite opposed in its chemical characters to the two bodies now described. Its principal characteristic is an indifference to all other substances, and an apparent reluctance to enter into combination with them. When forced by peculiar circumstances to do so, it seems to remain in the combination by a ***vis inertiæ;*** and very slight forces effect the disunion of these feeble compounds.

Yet nitrogen is an invariable constituent of plants, and during their life is subject to the control of the vital powers. But when the mysterious principle of life has ceased to exercise its influence, this element resumes its chemical character, and materially assists in promoting the decay of vegetable matter, by escaping from the compounds of which it formed a constituent.

Oxygen, the only remaining constituent of organic matter, is a gaseous element, which plays a most important part in the economy of nature. It is the agent employed in effecting the union and disunion of a vast number of compounds. It is superior to all other elements in the extensive range of its affinities. The phenomena of combustion and decay are examples of the exercise of its power.

Oxygen is the most generally diffused element on the surface of the earth; for, besides constituting the principal part of the atmosphere which surrounds it, it is a component of almost all the earths and minerals found on its surface. In an isolated state it is a gaseous body, possessed of neither taste nor smell. It is slightly soluble in water, and hence is usually found dissolved in rain and snow, as well as in the water of running streams.

Such are the principal characters of the elements which constitute organic matter; but it remains for us to consider in what form they are united in plants.

The substances which constitute the principal mass of every vegetable are compounds of carbon with oxygen and hydrogen, in the proper relative proportions for forming water. Woody fibre, starch, sugar, and gum, for example, are such compounds of carbon with the elements of water. In another class of substances containing carbon as an element, oxygen and hydrogen are again present; but the proportion of oxygen is greater than would be required for producing water by union with the hydrogen. The numerous organic acids met with in plants belong, with few exceptions, to this class

A third class of vegetable compounds contains carbon and hydrogen, but no oxygen, or less of that element than would be required to convert all the hydrogen into water. These may be regarded as compounds of carbon with the elements of water, and an excess of hydrogen. Such are the volatile and fixed oils, wax, and the resins. Many of them have acid characters.

The juices of all vegetables contain organic acids, generally combined with the

inorganic bases, or metallic oxides; for these metalic oxides exist in every plant, and may be detected in its ashes after incineration.

Nitrogen is an element of vegetable albumen and gluten; it is a constituent of the acid, and of what are termed the "indifferent substances" of plants, as well as of those peculiar vegetable compounds which possess all the properties of metallic oxides, and are known as "organic bases."

Estimated by its proportional weight, nitrogen forms only a very small part of plants; but it is never entirely absent from any part of them. Even when it does not absolutely enter into the composition of a particular part or organ, it is always to be found in the fluids which pervade it.

It follows from the facts thus far detailed, that the development of a plant requires the presence, first, of substances containing carbon and nitrogen, and capable of yielding these elements to the growing organism; secondly, of water and its elements; and lastly, of a soil to furnish the inorganic matters which are likewise essential to vegetable life.

OF THE COMPOSITION OF THE ATMOSPHERE.

In the normal state of growth plants can only derive their nourishment from the atmosphere and the soil. Hence it is of importance to be acquainted with the composition of these, in order that we may be enabled to judge from which of their constituents the nourishment is afforded.

The composition of the atmosphere has been examined by many chemists with great care, and the result of their researches have shown, that its principal constituents are always present in the same proportion. These are the two gases, oxygen and nitrogen, the general properties of which have been already described. One hundred parts, by weight, of atmospheric air contain 23·1 parts of oxygen, and 76·9 parts of nitrogen; or 100 volumes of air contain nearly 21 volumes of oxygen gas. From the extensive range of affinity which this gas possesses, it is obvious, that were it alone to constitute our atmosphere, and left unchecked to exert its powerful effects, all nature would be one scene of universal destruction. It is on this account that nitrogen is present in the air in so large proportion. It is peculiarly adapted for this purpose, as it does not possess any disposition to unite with oxygen, and exerts no action upon the processes proceeding on the earth. These two gases are intimately mixed, by virtue of a property which all gasses possess in common, of diffusing themselves equally through every part of another gas, with which they are placed in contact.

Although oxygen and nitrogen form the principal constituents of the atmosphere, yet they are not the only substances found in it. Watery vapour and carbonic acid gas materially modify its properties. The former of these falls upon the earth as rain, and brings with it any soluble matter which it meets in its passage through the air.

Carbonic acid gas is discharged in immense quantities from the active volcanoes of America, and from many of the mineral springs which abound in various parts of Europe; it is also generated during the combustion and decay of organic matter. It is not, therefore, surprising that it should have been detected in every part of the atmosphere in which its presence has been looked for. Saussure found it even in the air on the summit of Mont Blanc, which is covered with perpetual snow, and where it could not be produced by the immediate agency of vegetable matter. Carbonic acid gas performs a most important part in the process of vegetable nutrition, the consideration of which belongs to another part of the work.

Carbonic acid, water, and ammonia (a compound of hydrogen and nitrogen) are the final products of the decay of animal and vegetable matter. In an isolated condition, they usually exist in the gaseous form. Hence, on their formation, they must escape into the atmosphere. But ammonia has not hitherto been enumerated among the constituents of the air, although, according to our view, it can never be absent. The reason of this is, that it exists in extremely minute quantity in the amount of air usually subjected to experiment in chemical analysis; it has consequently escaped detection. But rain which falls through a large extent of air, carries down in solution all that remains in suspension in it. Now ammonia always exists in rainwater, and from this fact we must conclude that it is invariably present in the atmosphere. Nor can we be surprised at its presence when we consider that many volcanoes now in activity emit large quantities of it. This subject will, however, be discussed more fully in another part of the work.

Such are the principal constituents of the atmosphere from which plants derive their nourishment; for although other matters are supposed to exist in it in minute quantity, yet they do not exercise any influence on vegetation, nor has even their presence been satisfactorily demonstrated.

OF SOILS.

A soil may be considered a magazine of inorganic matters, which are prepared by the plant to suit the purposes destined for them in its nutrition. The composition and uses of such substances cannot, however, be studied with advantage, until we have considered the manner in which the organic matter is obtained by plants.

Some virgin soils, such as those of America, contain vegetable matter in large proportion; and as these have been found eminently adapted for the cultivation of most plants, the organic matter contained in them has naturally been recognised as the cause of their fertility. To this matter, the term "vegetable mould" or *humus* has been applied. Indeed, this peculiar substance appears to play such an important part in the phenomena of vegetation, that vegetable physiologists have been induced to ascribe the fertility of every soil to its presence. It is believed by many to be the principal nutriment of plants, and is supposed to be extracted by them from the soil in which they grow. It is itself the product of the decay of vegetable matter, and must, therefore, contain many of the constituents which are found in plants during life. Its action will, therefore, be examined in considering whence these constituents are derived.

CHAPTER II.

OF THE ASSIMILATION OF CARBON.

COMPOSITION OF HUMUS.

The humus, to which allusion has been made, is described by chemists as a brown substance easily soluble in alkalies, but only slightly so in water, and produced during the decomposition of vegetable matters by the action of acids or alkalies. It has, however, received various names according to the different external characters and chemical properties which it presents. Thus, *ulmin, humic acid, coal of humus*, and *humin*, are names applied to modifications of *humus*. They are obtained by treating peat, woody fibre, soot, or brown coal with alkalies; by decomposing sugar, starch, or sugar of milk by means of acids; or by exposing alkaline solutions of tannic and gallic acids to the action of the air.

The modifications of *humus* which are soluble in alkalies, are called *humic acid;* while those which are insoluble have received the designations of *humin* and *coal of humas*.

The names given to these substances might cause it to be supposed that their composition is identical. But a more erroneous notion could not be entertainad; since even sugar, acetic acid, and resin do not differ more widely in the proportions of their constituent elements, than do the various modifications of *humus*.

Humic acid formed by the action of hydrate of potash upon sawdust contains, according to the accurate analysis of Peligot, 72 per cent. of carbon, while the humic acid obtained from turf and brown coal contains, according to Sprengel, only 58 per cent.; that produced by the action of dilute sulphuric acid upon sugar, 57 per cent. according to Malaguti; and that, lastly, which is obtained from sugar or from starch, by means of muriatic acid, according to the analysis of Stein, 64 per cent. All these analyses have been repeated with care and accuracy, and the proportion of carbon in the respective cases has been found to agree with the estimates of the different chemists above mentioned; so that there is no reason to ascribe the difference in this respect between the varieties of *humus* to the mere difference in the methods of analysis or degrees of expertness of the operators. Malaguti states, moreover, that *humic acid* contains an equal number of equivalents of oxygen and hydrogen, that is to say, that these elements exist in it in the proportions for forming water; while, according to Sprengel, the oxygen is in excess, and Peligot even estimates the quantity of oxygen at 14 equivalents, and the hydrogen at only 6 equivalents, making the deficiency of hydrogen as great as 8 equivalents. And although Mulder* has very recently explained many of these conflicting results, by showing that there are several kinds of humus and humic acids essentially distinct in their characters, and fixed in their composition, yet he has afforded no proof that the definite compounds obtained by him really exist, as such, in the soil. On the contrary, they appear to have been formed by the action of the potash and ammonia, which he employed in their preparation.

It is quite evident, therefore, that chemists have been in the habit of designating all products of the decomposition of organic bodies which had a brown or brownish black colour, by the names of *humic acid* or *humin*, according as they were soluble or insoluble in alkalies; although in their composition and mode of origin, the substances thus confounded might be in no way allied.

Not the slightest ground exists for the belief that one or other of these artificial products of the decomposition of vegetable matters exists in nature in the form and endowed with the properties of the vegetable constituents of mould; there is not the shadow of a proof that one of them exerts any influence on the growth of plants either in the way of nourishment or otherwise.

Vegetable physiologists have, without any apparent reason, imputed the known properties of the *humus* and *humic acids* of chemists to that constituent of mould which has received the same name, and in this way have been led to their theoretical notions respecting the functions of the latter substance in vegetation.

The opinion that the substance called *humus* is extracted from the soil by the roots of plants, and that the carbon entering into its composition serves in some form or other to nourish their tissues, is considered by many as so firmly established that any new argument in its favour has been deemed unnecessary; the obvious difference in the growth of plants according to the known abundance or scarcity of *humus* in the soil.

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* Bulletin des Scienc. Phys. et Natur. de Neerl. 1840, p. 1—102.

seemed to afford incontestable proof of its correctness.*

Yet, this position, when submitted to a strict examination, is found to be untenable, and it becomes evident from most conclusive proofs that *humus* in the form in which it exists in the soil, does not yield the smallest nourishment to plants.

The adherence to the above incorrect opinion has hitherto rendered it impossible for the true theory of the nutritive process in vegetables to become known, and has thus deprived us of our best guide to a rational practice in agriculture. Any great improvement in that most important of all arts is inconceivable without a deeper and more perfect acquaintance with the substances which nourish plants, and with the sources whence they are derived; and no other cause can be discovered to account for the fluctuating and uncertain state of our knowledge on this subject up to the present time, than that modern physiology has not kept pace with the rapid progress of chemistry.

In the following inquiry we shall suppose the *humus* of vegetable physiologists to be really endowed with the properties recognised by chemists in the brownish black deposits which they obtain by precipitating an alkaline decoction of mould or peat by means of acids, and which they name *humic acid*.

Humic acid, when first precipitated, is a flocculent substance, is soluble in 2500 times its weight of water, and combines with alkalies, lime and magnesia, forming compounds of the same degree of solubility. (Sprengel.)

Vegetable physiologists agree in the supposition that by the aid of water *humus* is rendered capable of being absorbed by the roots of plants. But according to the observation of chemists, humic acid is soluble only when newly precipitated, and becomes completely insoluble when dried in the air, or when exposed in the moist state to the freezing temperature. (Sprengel.)

Both the cold of winter and the heat of summer, therefore, are destructive of the solubility of humic acid, and at the same time of its capability of being assimilated by plants. So that, if it is absorbed by plants, it must be in some altered form.

The correctness of these observations is easily demonstrated by treating a portion of good mould with cold water. The fluid remains colourless, and is found to have dissolved less than 100,000 part of its weight of organic matters, and to contain merely the salts which are present in rainwater.

Decayed oak wood, likewise, of which humic acid is the principal constituent, was found by Berzelius to yield to cold water only slight traces of soluble materials; and I have myself verified this observation on the decayed wood of beech and fir.

These facts, which show that humic, in its unaltered condition, cannot serve for the nourishment of plants, have not escaped the notice of physiologists; and hence they have assumed that the lime or the different alkalies found in the ashes of vegetables render soluble the humic acid and fit it for the process of assimilation.

Alkalies and alkaline earths do exist in the different kinds of soil in sufficient quantity to form such soluble compounds with the humic acid.

Now, let us suppose that humic acid is absorbed by plants in the form of that salt which contains the largest proportion of humic acid, namely, in the form of humate of lime, and then from the known quantity of the alkaline bases contained in the ashes of plants, let us calculate the amount of humic acid which might be assimilated in this manner. Let us admit, likewise, that potash, soda, and the oxides of iron and manganese have the same capacity of saturation as lime with respect to humic acid, and then we may take as the basis of our calculation the analysis of M. Berthier, who found that 1000 lbs. of dry fir wood yielded 4 lbs. of ashes, and that in every 100 lbs. of these ashes, after the chloride of potassium and sulphate of potash were extracted, 53 lbs. consisted of the basic metallic oxides, potash, soda, lime, magnesia, iron, and manganese.

One Hessian acre* of woodland yields annually, according to Dr. Heyer, on an average, 2920 lbs. of dry fir wood, which contain 6.17 lbs. of metallic oxides.

Now, according to the estimates of Malaguti and Sprengel, 1 lb. of lime combines chemically with 12 lbs. of humic acid; 6.17 lbs. of the metallic oxides would accordingly introduce into the trees 67 lbs. of humic acid, which, admitting humic acid to contain 58 per cent. of carbon, would correspond to 100 lbs. of dry wood. But we have seen that 2920 lbs. of fir wood are really produced.

Again, if the quantity of humic acid which might be introduced into wheat in the form of humates is calculated from the known proportion of metallic oxides existing in wheat straw, (the sulphates and chlorides also contained in the ashes of the straw not being included, it will be found that the wheat growing on 1 Hessian acre would receive in that way 63 lbs. of humic acid, corresponding to 93.6 lbs. of woody fibre. But the extent of land just mentioned produces, independently of the roots and grain, 1961 lbs. of straw, the composition of which is the same as that of woody fibre.

It has been taken for granted in these calculations that the basic metallic oxides which have served to introduce humic acid into the plants do not return to the soil, since it is certain that they remain fixed in the parts newly formed during the process of growth.

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* This remark applies more to German than to English botanists and physiologists. In England, the idea that humus, as such, affords nourishment to plants is by no means general; but on the Continent, the views of Berzelius on this subject have been almost universally adopted.—Ed.

* One Hessian acre is equal to 40,000 square feet, Hessian, or 26,910 square feet, English measure.

Let us now calculate the quantity of humic acid which plants can receive under the most favourable circumstances, viz. the agency of rainwater.

The quantity of rain which falls at Erfurt, one of the most fertile districts of Germany, during the months of April, May, June, and July, is stated by Schubler to be 19.3 lbs. over every square foot of surface; 1 Hessian acre, or 26,910 square feet, consequently receive 771,000 lbs. of rainwater.

If, now, we suppose that the whole quantity of this rain is taken up by the roots of a summer plant, which ripens four months after it is planted, so that not a pound of this water evaporates except from the leaves of the plant; and if we farther assume that the water thus absorbed is saturated with humate of lime (the most soluble of the humates, and that which contains the largest proportion of humic acid;) then the plants thus nourished would not receive more than 330 lbs. of humic acid, since one part of humate of lime requires 2500 parts of water for solution.

But the extent of land which we have mentioned produces 2843 lbs. of corn (in grain and straw, the roots not included,) or 22,000 lbs. of beet root (without the leaves and small radicle fibres.) It is quite evident that the 330 lbs. of humic acid, supposed to be absorbed, cannot account for the quantity of carbon contained in the roots and leaves alone, even if the supposition were correct, that the whole of the rainwater was absorbed by the plants. But since it is known that only a small portion of the rainwater which falls upon the surface of the earth evaporates through plants, the quantity of carbon which can be conveyed into them in any conceivable manner by means of humic acid must be extremely trifling, in comparison with that actually produced in vegetation.

Other considerations of a higher nature confute the common view respecting the nutritive office of humic acid, in a manner so clear and conclusive that it is difficult to conceive how it could have been so generally adopted.

Fertile land produces carbon in the form of wood, hay, grain, and other kinds of growth, the masses of which differ in a remarkable degree.

2920 lbs. of firs, pines, beeches, &c. grow as wood upon one Hessian acre of forest land with an average soil. The same superfices yields 2755 lbs. of hay.

A similar surface of corn land gives from 19,000 to 22,000 lbs. of beet root, or 881 lbs. of rye, and 1961 lbs. of straw, 160 sheaves of 15.4 lbs. each,—in all, 2843 lbs.

One hundred parts of dry fir wood contain 38 parts of carbon; therefore, 2920 lbs. contain 1109 lbs. of carbon.

One hundred parts of hay,* dried in air, contain 44.31 parts carbon. Accordingly, 2755 lbs. of hay contain 1111 lbs. of carbon.

Beet roots contain from 89 to 89.5 parts water, and from 10.5 to 11 parts solid matter, which consists of from 8 to 9 per cent sugar, and from 2 to 2½ per cent. cellular tissue. Sugar contains 42.4 per cent; cellular tissue, 47 per cent. of carbon.

22,000 lbs. of beet root, therefore, if they contain 9 per cent. of sugar, and 2 per cent of cellular tissue, would yield 1032 lbs. of carbon, of which 833 lbs. would be due to the sugar, and 198 lbs. to the cellular tissue; the carbon of the leaves and small roots not being included in the calculation.

One hundred parts of straw,† dried in air contain 38 per cent. of carbon; therefore, 1961 lbs. of straw contain 745 lbs. of carbon. One hundred parts of corn contain 43 parts of carbon; 882 lbs. must, therefore, contain 379 lbs.—in all, 1124 lbs. of carbon.

26,910 square feet of wood and meadow land produce, consepuently, 1109 lbs. of carbon; while the same extent of arable land yields in beet root, without leaves, 1032 lbs., or in corn, 1124 lbs.

It must be concluded from these incontestable facts, that equal surfaces of cultivated land of an average fertility produce equal quantities of carbon; yet, how unlike have been the different conditions of the growth of the plants from which this has been deduced!

Let us now inquire whence the grass in a meadow, or the wood in a forest, receives its carbon, since there no manure—no carbon—has been given to it as nourishment? and how it happens, that the soil, thus exhausted, instead of becoming poorer, becomes every year richer in this element?

A certain quantity of carbon is taken every year from the forest or meadow, in the form of wood or hay, and, in spite of this, the quantity of carbon in the soil augments; it becomes richer in humus.

It is said that in fields and orchards all the carbon which may have been taken away as herbs, as straw, as seeds, or as fruit, is replaced by means of manure; and yet this soil produces no more carbon than that of the forest or meadow, where it is never replaced. It cannot be conceived that the laws for the nutrition of plants are changed by culture,—that the sources of carbon for fruit or grain, and for grass or trees, are different.

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* 100 parts of hay, dried at 100° C. (212° F.) and burned with oxide of copper in a stream of oxygen gas, yielded 51.93 water, 165.8 carbonic acid, and 6.82 of ashes. This gives 45 87 carbon. 5.76 hydrogen, 31.55 oxygen, and 6.82 ashes. Hay, dried in the air, loses 11.2 p. c. water at 100° C. (212 F.)—(*Dr. Will.*)

† Straw analyzed in the same manner, and dried at 100° C., gave 46.37 p. c. of carbon, 5.68 p. c. of hydrogen, 43.93 p. c. of oxygen, and 4.02 p. c. of ashes. Straw dried in the air at 100° C. lost 18 p. c. of water.—*Dr. Will.*

It is not denied that manure exercises an influence upon the development of plants; but it may be affirmed with positive certainty, that it neither serves for the production of the carbon, nor has any influence upon it, because we find that the quantity of carbon produced by manured lands is not greater than that yielded by lands which are not manured. The discussion as to the manner in which manure acts has nothing to do with the present question, which is, the origin of the carbon. The carbon must be derived from other sources; and as the soil does not yield it, it can only be extracted from the atmosphere.

In attempting to explain the origin of carbon in plants, it has never been considered that the question is intimately connected with that of the origin of humus. It is universally admitted that humas arises from the decay of plants. No primitive humus, therefore, can have existed—for plants must have preceded the humus.

Now, whence did the first vegetables derive their carbon? and in what form is the carbon contained in the atmosphere?

These two questions involve the consideration of two most remarkable natural phenomena, which by their reciprocal and uninterrupted influence maintain the life of the individual animals and vegetables, and the continued existence of both kingdoms of organic nature.

One of these questions is connected with the invariable condition of the air with respect to oxygen. One hundred volumes of air have been found, at every period and in every climate, to contain 21 volumes of oxygen, with such small deviations that they must be ascribed to errors of observation.

Although the absolute quantity of oxygen contained in the atmosphere appears very great when represented by numbers, yet it is not inexhaustible. One man consumes by respiration 25 cubic feet of oxygen in 24 hours; 10 cwt. of charcoal consume 32,066 cubic feet of oxygen during its combustion; and a small town, like Giessen, (with about 7000 inhabitants) extracts yearly from the air, by the wood employed as fuel, more than 551 millions of cubic feet of this gas.

When we consider facts such as these, our former statement, that the quantity of oxygen in the atmosphere does not diminish in the course of ages*—that the air at the present day, for example, does not contain less oxygen than that found in jars buried for 1800 years in Pompeii—appears quite incomprehensible, unless some source exists whence the oxygen abstracted is replaced. How does it happen, then, that the proportion of oxygen in the atmosphere is thus invariable?

The answer to this question depends upon another; namely, what becomes of the carbonic acid, which is produced during the respiration of animals, and by the process of combustion? A cubic foot of oxygen gas, by uniting with carbon so as to form carbonic acid, does not change its volume. The billions of cubic feet of oxygen extracted from the atmosphere, produce the same number of billions of cubic feet of carbonic acid, which immediately supply its place.

The most exact and most recent experiments of De Saussure, made in every season for a space of three years, have shown, that the air contains on an average 0·000415 of its own volume of carbonic acid gas; so that, allowing for the inaccuracies of the experiments, which must diminish the quantity obtained, the proportion of carbonic acid in the atmosphere may be regarded as nearly equal to 1-1000 part of its weight. The quantity varies according to the seasons; but the yearly average remains continually the same.

We have no reason to believe that this proportion was less in past ages; and nevertheless, the immense masses of carbonic acid which annually flow into the atmosphere from so many causes, ought perceptibly to increase its quantity from year to year. But we find that all earlier observers describe its volume as from one-half to ten times greater than that which it has at the present time; so that we can hence at most conclude that it has diminished.

It is quite evident that the quantities of carbonic acid and oxygen in the atmosphere, which remain unchanged by lapse of time, must stand in some fixed relation to one another; a cause must exist which prevents the increase of carbonic acid by removing that which is constantly forming; and there must be some means of replacing the oxygen, which is removed from the air by the processes of combustion and putrefaction, as well as by the respiration of anmials.

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* If the atmosphere possessed, in its whole extent, the same density as it does on the surface of the sea, it would have a height of 24,555 Parisian feet; but it contains the vapour of water, so that we may assume its height to be one geographical mile = 22,843 Parisian feet. Now the radius of the earth is equal to 860 geographical miles; hence the

Volume of atmosphere = 9,307,500 cubic miles.
= cube of 210·4 miles.
Volume of oxygen = 1,954,578 cubic miles.
= cube of 125 miles.
Vol. of carbonic acid = 3,862·7 cubic miles.
= cube of 15·7 miles.

The maximum of the carbonic acid contained in the atmosphere has not here been adopted, but the mean, which is equal to 0·000415.

A man daily consumes 45,000 cubic inches (Parisian.) A man yearly consumes 9505·2 cubic feet. 100 million men yearly consume 9,505,200,000,000 cubic feet.

Hence a thousand million men yearly consume 0·79745 cubic miles of oxygen. But the air is rendered incapable of supporting the process of respiration, when the quantity of its oxygen is decreased 12 per cent.; so that a thousand million men would make the air unfit for respiration in a million years. The consumption of oxygen by animals, and by the process of combustion, is not introduced into the calculation.

Both these causes are united in the process of vegetable life.

The facts which we have stated in the preceding pages prove that the carbon of plants must be derived exclusively from the atmosphere. Now, carbon exists in the atmosphere only in the form of carbonic acid, and therefore, in a state of combination with oxygen.

It has been already mentioned likewise, that carbon and the elements of water form the principal constituents of vegetables; the quantity of the substances which do not possess this composition being in a very small proportion. Now, the relative quantity of oxygen in the whole mass is less than in carbonic acid; for the latter contains two equivalents of oxygen, while one only is required to unite with hydrogen in the proportion to form water. The vegetable products which contain oxygen in larger proportion than this, are, comparatively, few in number; indeed, in many the hydrogen is in great excess. It is obvious, that when the hydrogen of water is assimilated by a plant, the oxygen in combination with it must be liberated, and will afford a quantity of this element sufficient for the wants of the plant. If this be the case, the oxygen contained in the carbonic acid is quite unnecessary in the process of vegetable nutrition, and it will consequently escape into the atmosphere in a gaseous form. It is, therefore, certain, that plants must possess the power of decomposing carbonic acid, since they appropriate its carbon for their own use. The formation of their principal component substances must necessarily be attended with the separation of the carbon of the carbonic acid from the oxygen, which must be returned to the atmosphere, while the carbon enters into combination with water or its elements. The atmosphere must thus receive a volume of oxygen for every volume of carbonic acid which has been decomposed.

This remarkable property of plants has been demonstrated in the most certain manner, and it is in the power of every person to convince himself of its existence. The leaves and other green parts of a plant absorb carbonic acid, and emit an equal volume of oxygen. They possess this property quite independently of the plant; for if, after being separated from the stem, they are placed in water containing carbonic acid, and exposed in that condition to the sun's light, the carbonic acid is, after a time, found to have disappeared entirely from the water. If the experiment is conducted under a glass receiver filled with water, the oxygen emitted from the plant may be collected and examined. When no more oxygen gas is evolved, it is a sign that all the dissolved carbonic acid is decomposed; but the operation recommences if a new portion of it is added.

Plants do not emit gas when placed in water which either is free from carbonic acid, or contains an alkali that protects it from assimilation.

These observations were first made by Priestly and Sennebier. The excellent experiments of De Saussure have farther shown, that plants increase in weight during the decomposition of carbonic acid and separation of oxygen. This increase in weight is greater than can be accounted for by the quantity of carbon assimilated; a fact which confirms the view, that the elements of water are assimilated at the same time.

The life of plants is closely connected with that of animals, in a most simple manner, and for a wise and sublime purpose.

The presence of a rich and luxuriant vegetation may be conceived without the concurrence of animal life, but the existence of animals is undoubtedly dependent upon the life and development of plants.

Plants not only afford the means of nutrition for the growth and continuance of animal organization, but they likewise furnish that which is essential for the support of the important vital process of respiration; for, besides separating all noxious matters from the atmosphere, they are an inexhaustible source of pure oxygen, which supplies the loss which the air is constantly sustaining. Animals on the other hand expire carbon, which plants inspire; and thus the composition of the medium in which both exist, namely, the atmosphere, is maintained constantly unchanged.

It may be asked—is the quantity of carbonic acid in the atmosphere, which scarcely amounts to 1-10th per cent., sufficient for the wants of the whole vegetation on the surface of the earth,—is it possible that the carbon of plants has its origin from the air alone? This question is very easily answered. It is known, that a column of air of 2441 lbs. weight rests upon every square Hessian foot (=0.567 square foot English) of the surface of the earth; the diameter of the earth and its superficies are likewise known, so that the weight of the atmosphere can be calculated with the greatest exactness. The thousandth part of this is carbonic acid, which contains upwards of 27 per cent. carbon. By this calculation it can be shown, that the atmosphere contains 3306 billion lbs. of carbon; a quantity which amounts to more than the weight of all the plants, and of all the strata of mineral and brown coal, which exist upon the earth. This carbon is, therefore, more than adequate to all the purposes for which it is required. The quantity of carbon contained in seawater is proportionally still greater.

If, for the sake of argument, we suppose the superficies of the leaves and other green parts of plants, by which the absorption of carbonic acid is effected, to be double that of the soil upon which they grow, a supposition which is much under the truth in the case of woods, meadows, and corn fields; and if we farther suppose that carbonic acid equal to 0.00067 of the volume of the air, or 1-1000th of its weight is abstracted from it during every second of time, for eight hours daily, by a field of 53,814 square feet (= 2 Hessian acres;) then those leaves would receive 1102 lbs. of carbon in two hundred days.*

But it is inconceivable, that the functions of the organs of a plant can cease for any one moment during its life. The roots and other parts of it, which possess the same power, absorb constantly water and carbonic acid. This power is independent of solar light. During the day, when the plants are in the shade, and during the night, carbonic acid is accumulated in all parts of their structure; and the assimilation of the carbon and the exhalation of oxygen commence from the instant that the rays of the sun strike them. As soon as a young plant breaks through the surface of the ground, it begins to acquire colour from the top downwards; and the true formation of woody tissue commences at the same time.

The proper, constant, and inexhaustible sources of oxygen gas are the tropics and warm climates, where a sky, seldom clouded, permits the glowing rays of the sun to shine upon an immeasurably luxuriant vegetation. The temperate and cold zones, where artificial warmth must replace deficient heat of the sun, produce, on the contrary, carbonic acid in superabundance, which is expended in the nutrition of the tropical plants. The same stream of air, which moves by the revolution of the earth from the equator to the poles, brings to us in its passage from the equator, the oxygen generated there, and carries away the carbonic acid formed during our winter.

The experiments of De Saussure have proved, that the upper strata of the air contain more carbonic acid than the lower, which are in contact with plants; and that the quantity is greater by night than by day, when it undergoes decomposition.

Plants thus improve the air by the removal of carbonic acid, and by the renewal of oxygen, which is immediately applied to the use of man and animals. The horizontal currents of the atmosphere bring with them as much as they carry away, and the interchange of air between the upper and lower strata, which their difference of temperature causes, is extremely trifling when compared with the horizontal movements of the winds. Thus vegetable culture heightens the healthy state of a country, and a previously healthy country would be rendered quite uninhabitable by the cessation of all cultivation.

The various layers of wood and mineral coal, as well as peat, form the remains of a primeval vegetation. The carbon which they contain must have been originally in the atmosphere as carbonic acid in which form it was assimilated by the plants which constitute these formations. It follows from this, that the atmosphere must be richer in oxygen at the present time than in former periods of the earth's history. The increase must be exactly proportional to the quantity of carbon and hydrogen contained in these carboniferous deposits. Thus, during the formation of 353 cubic feet of Newcastle splint coal, the atmosphere must have received 643 cubic feet of oxygen produced from the carbonic acid assimilated, and also 158 cubic feet of the same gas resulting from the decomposition of water. In former ages, therefore, the atmosphere must have contained less oxygen, but a much larger proportion of carbonic acid, than it does at the present time, a circumstance which accounts for the richness and luxuriance of the earlier vegetation.

But a certain period must have arrived in which the quantity of carbonic acid contained in the air experienced neither increase nor diminution in any appreciable quantity. For if it received an additional quantity to its usual proportion, an increased vegetation would be the natural consequence, and the excess would thus be speedily removed. And, on the other hand, if the gas was less than the normal quantity, the progress of vegetation would be retarded, and the proportion would soon attain its proper standard.

The most important function in the life of plants, or, in other words, in their assimilation of carbon, is the separation, we might almost say the generation, of oxygen. No matter can be considered as nutritious, or as necessary to the growth of plants, which possesses a composition either similar to or identical with theirs, and the assimilation of which, therefore, could take place without exercising this function. The reverse is the case in the nutrition of ani mals. Hence such substances as sugar, starch, and gum, which are themselves products of plants, cannot be adopted for assimilation. And this is rendered certain by the experiments of vegetable physiologists, who have shown that aqueous solutions of these bodies are imbibed by the roots of plants, and carried to all parts of their structure, but are not assimilated, they cannot, therefore, be employed in their nutrition. We could scarcely conceive a form more convenient for assimilation than that of gum, starch, and sugar, for they all contain the elements of woody fibre, and nearly in the same proportions.

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* The quantity of carbonic acid which can be extracted from the air in a given time, is shown by the following calculation. During the whitewashing of a small chamber, the superficies of the walls and roof of which we will suppose to be 105 square metres, and which receives six coats of lime in four days, carbonic acid is abstracted from the air, and the lime is consequently converted, on the surface, into a carbonate. It has been accurately determined that one square decimetre receives in this way, a coating of carbonate of lime which weighs 0.732 grammes. Upon the 105 square metres already mentioned there must accordingly be formed 7686 grammes of carbonate of lime. which contain 4325.6 grammes of carbonic acid. The weight of one cubic decimetre of carbonic acid being calculated at two grammes, (more accurately 1.97978.) the above mentioned surface must absorb in four days 2.163 cubic metres of carbonic acid. 2500 square metres (one Hessian acre) would absorb, under a similar treatment, 51½ cubic metres=1818 cubic feet of carbonic acid in four days. In 200 days it would absorb 2575 cubic metres=904,401 cubic feet, which contain 11,353 lbs. of carbonic acid, of which 3304 lbs. are carbon, a quantity three times as great as that which is assimilated by the leaves and roots growing upon the same space.

In the second part of the work we shall adduce satisfactory proofs that decayed woody fibre (*humus*) contains carbon and the elements of water, without an excess of oxygen; its composition differing from that of woody fibre in its being richer in carbon.

Misled by this simplicity in its constitution, physiologists found no difficulty in discovering the mode of the formation of woody fibre; for they say,* humus has only to enter into combination with water, in order to effect the formation of woody fibre, and other substances similarly composed, such as sugar, starch, and gum. But they forget that their own experiments have sufficiently demonstrated the inaptitude of these substances for assimilation.

All the erroneous opinions concerning the *modus operandi* of humus have their origin in the false notions entertained respecting the most important vital functions of plants; analogy, that fertile source of error, having, unfortunately, led to the very unapt comparison of the vital functions of plants with those of animals.

Substances, such as sugar, starch, &c., which contain carbon and the elements of water, are products of the life of plants which live only while they generate them. The same may be said of humus, for it can be formed in plants like the former substances. Smithson, Jameson, and Thomson, found that the black excretions of unhealthy elms, oaks, and horse chesnuts, consisted of humic acid in combination with alkalies. Berzelius detected similar products in the bark of most trees. Now, can it be supposed that the diseased organs of a plant possess the power of generating the matter to which its substance and vigour are ascribed?

How does it happen, it may be asked, that the absorption of carbon from the atmosphere by plants is doubted by all botanists and vegetable physiologists, and that by the greater number the purification of the air by means of them is wholly denied?

The action of plants on the air in the absence of light, that is during night, has been much misconceived by botanists, and from this we may trace most of the errors which abound in the greater part of their writings. The experiments of Ingenhouss were in a great degree the cause of this uncertainty of opinion regarding the influence of plants in purifying the air. His observation that green plants emit carbonic acid in the dark, led De Saussure and Grischow to new investigations, by which they ascertained that under such conditions plants do really absorb oxygen and emit carbonic acid; but that the whole volume of air undergoes diminution at the same time. From the latter fact it follows, that the quantity of oxygen gas absorbed is greater than the volume of carbonic acid separated; for, if this were not the case, no diminution could occur. These facts cannot be doubted, but the views based on them have been so false, that nothing, except the total want of observation and the utmost ignorance of the chemical relations of plants to the atmosphere, can account for their adoption.

It is known that nitrogen, hydrogen, and a number of other gases, exercise a peculiar, and in general, an injurious influence upon living plants. Is it, then, probable, that oxygen, one of the most energetic agents in nature, should remain without influence on plants when one of their peculiar processes of assimilation has ceased?

It is true that the decomposition of carbonic acid is arrested by absence of light. But then, namely, at night, a true chemical process commences, in consequence of the action of the oxygen in the air, upon the organic substances composing the leaves, blossoms, and fruit. This process is not at all connected with the life of the vegetable organism, because it goes on in a dead plant exactly as in a living one.

The substances composing the leaves of different plants being known, it is a matter of the greatest ease and certainty to calculate which of them, during life, should absorb most oxygen by chemical action when the influence of light is withdrawn.

The leaves and green parts of all plants containing volatile oils or volatile constituents in general, which change into resin by the absorption of oxygen, should absorb more than other parts which are free from such substances. Those leaves, also, which contain either the constituents of nutgalls, or compounds in which nitrogen is present, ought to absorb more oxygen than those which do not contain such matters. The correctness of these inferences has been distinctly proved by the observations of De Saussure; for, while the tasteless leaves of the *Agave americana* absorb only 0·3 of their volume of oxygen in the dark, during 24 hours, the leaves of the *Pinus Abies*, which contain volatile and resinous oils, absorb 10 times, those of the *Quercus Robur* containing tannic acid 14 times, and the balmy leaves of the *Populus alba* 21 times that quantity. This chemical action is shown very plainly also, in the leaves of the *Cotyledon calycinum*, the *Cacalia ficoides*, and others; for they are sour like sorrel in the morning, tasteless at noon, and bitter in the evening. The formation of acids is effected during the night by a true process of oxidation: these are deprived of their acid properties during the day and evening, and are changed by separation of a part of their oxygen into compounds containing oxygen and hydrogen, either in the same proportions as in water, or even with an excess of hydrogen, which is the composition of all tasteless and bitter substances.

Indeed, the quantity of oxygen absorbed could be estimated pretty nearly by the different periods which the green leaves of plants require to undergo alteration in colour, by the influence of the atmosphere. Those which continue longest green will abstract less oxygen from the air in an equal space of time, than those the constituent parts of which suffer a more rapid change. It is found, for example, that the leaves of the *Ilex aquifolium*, distinguished by the durability of their colour, absorb only 0·86 of their volume of oxygen gas in the same time that the leaves of the poplar absorb 8, and those of the beech $9\frac{1}{2}$ times their volume; both the beech and poplar being remarkable for the rapidity and ease with which the colour of their leaves changes.

When the green leaves of the poplar, the beech, the oak, or the holly, are dried under the air pump, with exclusion of light, then moistened with water, and placed under a glass globe filled with oxygen, they are found to absorb that gas in proportion as they change in colour. The chemical nature of this process is thus completely established. The diminution of the gas which occurs can only be owing to the union of a large proportion of oxygen with those substances which are already in the state of oxides, or to the oxidation of the hydrogen in those vegetable compounds which contain it in excess. The fallen brown or yellow leaves of the oak contain no longer tannin, and those of the poplar no balsamic constituents.

The property which green leaves possess of absorbing oxygen belongs also to fresh wood, whether taken from a twig or from the interior of the trunk of a tree. When fine chips of such wood are placed in a moist condition under a jar filled with oxygen, the gas is seen to diminish in volume. But wood, dried by exposure to the atmosphere and then moistened, converts the oxygen into carbonic acid, without change of volume; fresh wood, therefore, absorbs most oxygen.

MM. Petersen and Schödler have shown, by the careful elementary analysis of 24 different kinds of wood, that they contain carbon and the elements of water, with the addition of a certain quantity of hydrogen. Oak wood, recently taken from the tree, and dried at 100° C. (212 F.,) contains 49,432 carbon, 6.069 hydrogen, and 44.499 oxygen.

The proportion of hydrogen which is necessary to combine with 44.498 oxygen in order to form water, is $\frac{1}{8}$ of this quantity, namely, 5.56; it is evident, therefore, that oak wood contains $\frac{1}{12}$ more hydrogen than corresponds to this proportion. In *Pinus Larix*, *P. Abies*, and *P. picea* the excess of hydrogen amounts to $\frac{1}{7}$, and in *Tilia europæa* to $\frac{1}{5}$. The quantity of hydrogen stands in some relation to the specific weight of the wood; the lighter kinds of wood contain more of it than the heavier. In ebony wood (*Diospyros Ebenum*) the oxygen and hydrogen are in exactly the same proportion as in water.

The difference between the composition of the varieties of wood, and that of simple woody fibre, depends, unquestionably, upon the presence of constituents, in part soluble, and in part insoluble, such as resin and other matters, which contain a large proportion of hydrogen: the hydrogen of such substances being in the analysis of the various woods superadded to that of the true woody fibre.

It has previously been mentioned that mouldering oak wood contains carbon and the elements of water, without any excess of hydrogen. But the proportions of its constituents must necessarily have been different, if the volume of the air had not changed during its decay, because the proportion of hydrogen in those component substances of the wood which contained it in excess is here diminished, and this diminution could only be effected by an absorption of oxygen, and consequent formation of water.

Most vegetable physiologists have connected the emission of carbonic acid during the night with the absorption of oxygen from the atmosphere, and have considered these actions as a true process of respiration in plants, similar to that of animals, and like it, having for its result the separation of carbon from some of their constitutents. This opinion has a very weak and unstable foundation.

The carbonic acid, which has been absorbed by the leaves and by the roots, together with water, ceases to be decomposed on the departure of daylight; it is dissolved in the juices which pervade all parts of the plant, and escapes every moment through the leaves in quantity corresponding to that of the water which evaporates.

A soil in which plants vegetate vigorously, contains a certain quantity of moisture which is indispensably necessary to their existence. Carbonic acid, likewise, is always present in such a soil, whether it has been abstracted from the air or has been generated by the decay of vegetable matter. Rain and wellwater, and also that from other sources, invariably contains carbonic acid. Plants during their life constantly possess the power of absorbing by their roots moisture, and, along with it, air and carbonic acid. Is it, therefore, surprising that the carbonic acid should be returned unchanged to the atmosphere, along with water, when light (the cause of the fixation of its carbon) is absent?

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* Meyen, *Pflanzenphysiologie*, II. S. 141.

Neither this emission of carbonic acid nor the absorption of oxygen has any connection with the process of assimilation; nor have they the slightest relation to one another; the one is a purely mechanical, the other a purely chemical process. A cotton wick, inclosed in a lamp, which contains a liquid saturated with carbonic acid, acts exactly in the same manner as a living plant in the night. Water and carbonic acid are sucked up by capillary attraction, and both evaporate from the exterior part of the wick.

Plants which live in a soil containing humus exhale much more carbonic acid during the night than those which grow in dry situations; they also yield more in rainy than in dry weather. These facts point out to us the cause of the numerous contradictory observations, which have been made with respect to the change impressed upon the air by living plants, both in darkness and in common daylight, but which are unworthy of consideration, as they do not assist in the solution of the main question.

There are other facts which prove in a decisive manner that plants yield more oxygen to the atmosphere than they extract from it; these proofs, however, are to be drawn with certainty only from plants which live under water.

When pools and ditches, the bottoms of which are covered with growing plants, freeze upon their surface in winter, so that the water is completely excluded from the atmosphere by a clear stratum of ice, small bubbles of gas are observed to escape, continually, during the day, from the points of the leaves and twigs. These bubbles are seen most distinctly when the rays of the sun fall upon the ice; they are very small at first, but collect under the ice and form larger bubbles. They consist of pure oxygen gas. Neither during the night, nor during the day when the sun does not shine, are they observed to diminish in quantity. The source of this oxygen is the carbonic acid dissolved in the water, which is absorbed by the plants, but is again supplied to the water, by the decay of vegetable substances contained in the soil. If these plants absorb oxygen during the night, it can be in no greater quantity than that which the surrounding water holds in solution, for the gas, which has been exhaled, is not again absorbed. The action of water plants cannot be supposed to form an exception to a great law of nature, and the less so, as the different action of aerial plants upon the atmosphere is very easily explained.

The opinion is not new that the carbonic acid of the air serves for the nutriment of plants, and that its carbon is assimilated by them; it has been admitted, defended, and argued for, by the soundest and most intelligent natural philosophers, namely, by Priestley, Sennebier, De Saussure, and even by Ingenhouss himself. There scarcely exists a theory in natural science, in favour of which there are more clear and decisive arguments. How, then, are we to account for its not being received in its full extent by most other physiologists, for its being even disputed by many, and considered by a few as quite refuted?

All this is due to two causes, which we shall now consider.

One is, that in botany the talent and labour of inquirers has been wholly spent in the examination of form and structure: chemistry and physics have not been allowed to sit in council upon the explanation of the most simple processes; their experience and their laws have not been employed, though the most powerful means of help in the acquirement of true knowledge. They have not been used, because their study has been neglected.

All discoveries in physics and in chemistry, all explanations of chemists, must remain without fruit and useless, because, even to the great leaders in physiology, carbonic acid, ammonia, acids, and bases, are sounds without meaning, words without sense, terms of an unknown language, which awaken no thoughts and no associations. They treat these sciences like the vulgar, who despise a foreign literature in exact proportion to their ignorance of it; since even when they have had some acquintance with them, they have not understood their spirit and application.

Physiologists reject the aid of chemistry in their inquiry into the secrets of vitality, although it alone could guide them in the true path; they reject chemistry, because in its pursuit of knowledge it destroys the subjects of its investigation; but they forget that the knife of the anatomist must dismember the body, and destroy its organs, if an account is to be given of their form, structure, and functions.

When pure potato starch is dissolved in nitric acid, a ring of the finest wax remains. What can be opposed to the conclusion of the chemist, that each grain of starch consists of concentric layers of wax and amylin, which thus mutually protect each other against the action of water and ether? Can results of this kind, which illustrate so completely both the nature and properties of bodies, be attained by the microscope? Is it possible to make the gluten in a piece of bread visible in all its connections and ramifications? It is impossible by means of instruments; but if the piece of bread is placed in a lukewarm decoction of malt, the starch, and the substance called dextrine,* are seen to dissolve like sugar in water, and, at last, nothing remains except the gluten, in the

form of a spongy mass, the minute pores of which can be seen only by a microscope.

Chemistry offers innumerable resources of this kind which are of the greatest use in an inquiry into the nature of the organs of plants; but they are not used, because the need of them is not felt. The most important organs of animals and their functions are known, although they may not be visible to the naked eye. But in vegetable physiology, a leaf is in every case regarded merely as a leaf, notwithstanding that leaves generating oil of turpentine or oil of lemons must possess a different nature from those in which oxalic acid is formed. Vitality, in its peculiar operations, makes use of a special apparatus for each function of an organ. A rose twig engrafted upon a lemon tree does not bring forth lemons, but roses. Vegetable physiologists in the study of their science have not directed their attention to that part of it which is most worthy of investigation.

The second cause of the incredulity with which physiologists view the theory of the nutrition of plants by the carbonic acid of the atmosphere is, that the art of experimenting is not known in physiology, it being an art which can be learned accurately only in the chemical laboratory. Nature speaks to us in a peculiar language, in the language of phenomena; she answers at all times the questions which are put to her; and such questions are experiments. An experiment is the expression of a thought: we are near the truth when the phenomena elicited by the experiment corresponds to the thought; while the opposite result shows that the question was falsely stated, and that the conception was erroneous.

The critical repetition of another's experiments must be viewed as a criticism of his opinions; if the result of the criticism be merely negative, if it do not suggest more correct ideas in the place of those which it is intended to refute, it should be disregarded; because the worse experimenter the critic is, the greater will be the discrepancy between the results he obtains and the views proposed by the other.

It is too much forgotten by physiologists, that their duty really is not to refute the experiments of others, nor to show that they are erroneous, but to discover truth, and that alone. It is startling, when we reflect that all the time and energy of a multitude of persons of genius, talent, and knowledge, are expended in endeavours to demonstrate each other's errors.

The question whether carbonic acid is the food of plants or not has been made the subject of experiments with perfect zeal and good faith; the results have been opposed to that view. But how was the inquiry instituted?

The seeds of balsamines, beans, cresses, and gourds, were sown in pure Carrara marble, and sprinkled with water containing carbonic acid. The seeds sprang, but the plants did not attain to the development of the third small leaf. In other cases, they allowed the water to penetrate the marble from below, yet, in spite of this, they died. It is worthy of observation, that they lived longer with pure distilled water than with that impregnated with carbonic acid; but still, in this case also, they eventually perished. Other experimenters sowed seeds of plants in flowers of sulphur and sulphate of barytes, and tried to nourish them with carbonic acid, but without success.

Such experiments have been considered as positive proofs, that carbonic acid will not nourish plants; but the manner in which they were instituted is opposed to all rules of philosophical inquiry, and to all the laws of chemistry.

Many conditions are necessary for the life of plants; those of each genus require special conditions; and should but one of these be wanting, although the rest be supplied, the plants will not be brought to maturity. The organs of a plant, as well as those of an animal, contain substances of the most different kinds; some are formed solely of carbon and the elements of water, others contain nitrogen, and in all plants we find metallic oxides in the state of salts. The food which can serve for the production of all the organs of a plant, must necessarily contain all its elements. These most essential of all the chemical qualities of nutriment may be united in one substance, or they may exist separately in several; in which case, the one contains what is wanting in the other. Dogs die although fed with jelly, a substance which contains nitrogen; they cannot live upon white bread, sugar or starch, if these are given as food, to the exclusion of all other substances. Can it be concluded from this, that these substances contain no elements suited for assimilation? Certainly not.

Vitality is the power which each organ possesses of constantly reproducing itself; for this it requires a supply of substances which contain the constituent elements of its own substance, and are capable of undergoing transformation. All the organs together cannot generate a single element, carbon, nitrogen, or a metallic oxide.

When the quantity of the food is too great, or is not capable of undergoing the necessary transformation, or exerts any peculiar chemical action, the organ itself is subjected to a change: all poisons act in this manner. The most nutritious substances may cause death. In experiments such as those described above, every condition of nutrition should be considered. Besides those matters which form their principal constituent parts, both animals and plants require others, the peculiar functions of which are unknown. These are inorganic substances, such as common salt, the total want of which is in animals inevitably productive of death. Plants, for the same reason, cannot live unless supplied with certain metallic compounds.

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* According to Raspail, starch consists of vesicles inclosing within them a fluid resembling gum. Starch may be put in cold water without being dissolved: but, when placed in hot water, these spherules burst, and allow the escape of the liquid. This liquid is the *dextrine* of Biot, so called because it possesses the property of turning the plane of the polarization of light to the right hand. —Ed.

If we knew with certainty that there existed a substance capable alone of nourishing a plant and of bringing it to maturity, we might be led to a knowledge of the conditions necessary to the life of all plants, by studying its characters and composition. If humus were such a substance, it would have precisely the same value as the only single food which nature has produced for animal organization, namely, milk (Prout.) The constituents of milk are cheese or caseine, a compound containing nitrogen in large proportion; butter, in which hydrogen abounds; and sugar of milk, a substance with a large quantity of hydrogen and oxygen in the same proportion as in water. It also contains in solution, lactate of soda, phosphate of lime, and common salt; and a peculiar aromatic product exists in the butter, called butyric acid. The knowledge of the composition of milk is a key to the conditions necessary for the purposes of nutrition of all animals.

All substances which are adequate to the nourishment of animals contain those materials united, though not always in the same form; nor can any one be wanting for a certain space of time, without a marked effect on the health being produced. The employment of a substance as food presupposes a knowledge of its capacity of assimilation, and of the conditions under which this takes place.

A carnivorous animal dies in the vacuum of an air pump, even though supplied with a superabundance of food; it dies in the air, if the demands of its stomach are not satisfied; and it dies in pure oxygen gas, however lavishly nourishment be given to it. Is it hence to be concluded, that neither flesh, nor air, nor oxygen, is fitted to support life? Certainly not.

From the pedestal of the Trajan column at Rome we might chisel out each single piece of stone, if upon the extraction of the second we replaced the first. But could we conclude from this that the column was suspended in the air, and not supported by a single piece of its foundation? Assuredly not. Yet the strongest proof would have been given that each portion of the pedestal could be removed, without the downfall of the column.

Animal and vegetable physiologists, however, come to such conclusions with respect to the process of assimilation. They institute experiments, without being acquainted with the circumstances necessary for the continuance of life—with the qualities and proper nutriment of the animal or plant on which they operate—or with the nature and chemical constitution of its organs. These experiments are considered by them as convincing proofs, while they are fitted only to awaken pity.

Is it possible to bring a plant to maturity by means of carbonic acid and water, without the aid of some substance containing nitrogen, which is an essential constituent of the sap, and indispensable for its production? Must the plant not die, however abundant the supply of carbonic acid may be, as soon as the first small leaves have exhausted the nitrogen contained in the seeds?

Can a plant be expected to grow in Carrara marble, even when an azotised substance is supplied to it, if the marble be sprinkled with an aqueous solution of carbonic acid, which dissolves the lime and forms bicarbonate of lime? A plant of the family of the *Plumbagineæ*, upon the leaves of which fine hornlike, or scaly processes of crystallised carbonate of lime are formed, might, perhaps, attain maturity under such circumstances; but these experiments are only sufficient to prove, that cresses, gourds, and balsamines, cannot be nourished by bicarbonate of lime, in the absence of matter containing nitrogen. We may, indeed, conclude, that the salt of lime acts as a poison, since the developement of plants will advance farther in pure water, when lime and carbonic acid are not used.

Moist flowers of sulphur attract oxygen from the atmosphere, and become acid. Is it possible that a plant can grow and flourish in presence of free sulphuric acid, with no other nourishment than carbonic acid? It is true, the quantity of sulphuric acid formed thus in hours, or in days, may be small, but the property of each particle of the sulphur to absorb oxygen and retain it, is present every moment.

When it is known that plants require moisture, carbonic acid, and air, should we choose as the soil for experiments on their growth, sulphate of barytes, which, from its nature and specific gravity, completely prevents the access of air?

All these experiments are valueless for the decision of any question. It is absurd to take for them any soil, at mere hazard, as long as we are ignorant of the functions performed in plants by those inorganic substances which are apparently foreign to them. It is quite impossible to mature a plant of the family of the *Gramineæ*, or of the *Equisetaceæ*, the solid framework of which contains silicate of potash, without silicic acid and potash, or a plant of the genus *Oxalis* without potash, or saline plants such as the saltworts (*Salsola* and *Salicornia*) without chloride of sodium, or at least some salt of similar properties. All seeds of the *Gramineæ* contain phosphate of magnesia; the solid parts of the roots of the *althæa* contain more phosphate of lime than woody fibre. Are these substances merely accidentally present? A plant should not be chosen for experiment, when the matter which it requires for its assimilation is not well known.

What value, now, can be attached to experiments in which all those matters which a plant requires in the process of assimilation, besides its mere nutriment, have been

excluded with the greatest care? Can the laws of life be investigated in an organised being which is diseased or dying?

The mere observation of a wood or meadow is infinitely better adapted to decide so simple a question than all the trivial experiments under a glass globe; the only difference is that instead of one plant there are thousands. When we are acquainted with the nature of a single cubic inch of their soil, and know the composition of the air and rainwater, we are in possession of all the conditions necessary to their life. The source of the different elements entering into the composition of plants cannot possibly escape us, if we know in what form they take up their nourishment, and compare its composition with that of the vegetable substances which compose their structure.

All these questions will now be examined and discussed. It has been already shown that the carbon of plants is derived from the atmosphere: it still remains for us to inquire what power is exerted on vegetation by the humus of the soil and the inorganic constituents of plants and also to trace the sources of their nitrogen.

CHAPTER III.

ON THE ORIGIN AND ACTION OF HUMUS.

It will be shown in the second part of this work, that all plants and vegetable structures undergo two processes of decomposition after death. One of these is named *fermentation;* the other, *putrefaction, decay,* or *eremacausis.*[*]

It will likewise be shown, that decay is a slow process of combustion,—a process, therefore, in which the combustible parts of a plant unite with the oxygen of the atmosphere.

The decay of woody fibre (the principal constituent of all plants) is accompanied by a phenomenon of a peculiar kind. This substance, in contact with air or oxygen gas, converts the latter into an equal volume of carbonic acid, and its decay ceases upon the disappearance of the oxygen. If the carbonic acid is removed, and oxygen replaced, its decay recommences, that is, it again converts oxygen into carbonic acid. Woody fibre consists of carbon and the elements of water; and if we judge only from the products formed during its decomposition, and from those formed by pure charcoal, burned at a high temperature, we might conclude that the causes were the same in both: the decay of woody fibre proceeds, therefore, as if no hydrogen or oxygen entered into its composition.

A very long time is required for the completion of this process of combustion, and the presence of water is necessary for its maintenance: alkalies promote it, but acids retard it; all antiseptic substances, such as sulphurous acid, the mercurial salts, empyreumatic oils, &c., cause its complete cessation.

Woody fibre in a state of decay is the substance called *humus.*[*]

The property of woody fibre to convert surrounding oxygen gas into carbonic acid diminishes in proportion as its decay advances, and at last a certain quantity of a brown coaly-looking substance remains, in which this property is entirely wanting. This substance is called *mould;* it is the product of the complete decay of woody fibre. Mould constitutes the principal of all the strata of brown coal and peat.

Humus acts in the same manner in a soil permeable to air as in the air itself; it is a continued source of carbonic acid, which it emits very slowly. An atmosphere of carbonic acid, formed at the expense of the air, surrounds every particle of decaying humus. The cultivation of land, by tilling and loosening the soil, causes a free and unobstructed access of air. An atmosphere of carbonic acid is, therefore, contained in every fertile soil, and is the first and most important food for the young plants which grow in it.

In spring, when those organs of plants are absent which nature has appointed for the assumption of nourishment from the atmosphere, the component substance of the seeds is exclusively employed in the formation of the roots. Each new radicle fibril which a plant acquires may be regarded as constituting at the same time a mouth, a lung, and a stomach. The roots perform the functions of the leaves from the first moment of their formation: they extract from the soil their proper nutriment, namely, the carbonic acid generated by the humus.

By loosening the soil which surrounds young plants, we favour the access of air, and the formation of carbonic acid; and, on the other hand, the quantity of their food is diminished by every difficulty which opposes the renewal of air. A plant itself effects this change of air at a certain period of its growth. The carbonic acid, which protects the undecayed humus from farther change, is absorbed and taken away by the fine fibres of the roots, and by the roots themselves; this is replaced by atmospheric air, by which process the decay is renewed, and a fresh portion of carbonic acid formed. A plant at this time receives its food both by the roots and by the organs above ground, and advances rapidly to maturity.

When a plant is quite matured, and when

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[*] The word *eremacausis* was proposed by the author some time since, in order to explain the true nature of decay; it is compounded from ἠρέμα, *by degrees* and καυσις, *burning.*

[*] The humic acid of chemists is a product of the decomposition of humus by alkalies; it does not exist in the humus of vegetable physiologists.

the organs by which it obtains food from the atmosphere are formed, the carbonic acid of the soil is no farther required.

Deficiency of moisture in the soil, or its complete dryness, does not now check the growth of a plant, provided it receives from the dew and the atmosphere as much as is requisite for the process of assimilation. During the heat of summer it derives its carbon exclusively from the atmosphere.

We do not know what height and strength nature has allotted to plants; we are acquainted only with the size which they usually attain. Oaks are shown, both in London and Amsterdam, as remarkable curiosities, which have been reared by Chinese gardeners, and are only one foot and a half in height, although their trunks, barks, leaves, branches, and whole habitus, evince a venerable age. The small parsnep grown at Teltow,* when placed in a soil which yields as much nourishment as it can take up, increases to several pounds in weight.

The size of a plant is proportional to the surface of the organs which are destined to convey food to it. A plant gains another mouth and stomach with every new fibre of root, and every new leaf.

The power which roots possess of taking up nourishment does not cease as long as nutriment is present. When the food of a plant is in greater quantity than its organs require for their own perfect development, the superfluous nutriment is not returned to the soil, but is employed in the formation of new organs. At the side of a cell, already formed, another cell arises; at the side of a twig and leaf, a new twig and a new leaf are developed. These new parts could not have been formed had there not been an excess of nourishment. The sugar and mucilage produced in the seeds, form the nutriment of the young plants, and disappear during the development of the buds, green sprouts, and leaves.

The power of absorbing nutriment from the atmosphere, with which the leaves of plants are endowed, being proportionate to the extent of their surface, every increase in the size and number of these parts is necessarily attended with an increase of nutritive power, and a consequent farther development of new leaves and branches. Leaves, twigs, and branches, when completely matured, as they do not become larger, do not need food for their support. For their existence as organs, they require only the means necessary for the performance of the special functions to which they are destined by nature; they do not exist on their own account.

We know that the functions of the leaves and other green parts of plants are to absorb carbonic acid, and with the aid of light and moisture, to appropriate its carbon. These processes are continually in operation; they commence with the first formation of the leaves, and do not cease with their perfect development. But the new products arising from this continued assimilation are no longer employed by the perfect leaves in their own increase: they serve for the formation of woody fibre, and all the solid matters of similar composition. The leaves now produce sugar, amylin or starch, and acids, which were previously formed by the roots when they were necessary for the development of the stem, buds, leaves, and branches of the plant.

The organs of assimilation, at this period of their life, receive more nourishment from the atmosphere than they employ in their own sustenance; and when the formation of the woody substance has advanced to a certain extent, the expenditure of the nutriment, the supply of which still remains the same, takes a new direction, and blossoms are produced. The functions of the leaves of most plants cease upon the ripening of their fruit, because the products of their action are no longer needed. They now yield to the chemical influence of the oxygen of the air, generally suffer a change in colour, and fall off.

A peculiar "transformation" of the matters contained in all plants takes place in the period between blossoming and the ripening of the fruit; new compounds are produced, which furnish constituents of the blossoms, fruit, and seed. An organic chemical "transformation" is the separation of the elements of one or several combinations, and their re-union into two or several others, which contain the same number of elements, either grouped in another manner, or in different proportions. Of two compounds formed in consequence of such a change, one remains as a component part of the blossom or fruit, while the other is separated by the roots in the form of excrementitious matter. No process of nutrition can be conceived to subsist in animals or vegetables, without a separation of effete matters. We know, indeed, that an organized body cannot generate substances, but can only change the mode of their combination, and that its sustenance and reproduction depend upon the chemical transformation of the matters which are employed as its nutriment, and which contain its own constituent elements.

Whatever we regard as the cause of these transformations, whether the Vital Principle, Increase of Temperature, Light, Galvanism, or any other influence, the act of transformation is a purely chemical process. Combination and Decomposition can take place only when the elements are disposed to these changes. That which chemists name *affinity* indicates only the degree in which they possess this disposition. It will be shown, when considering the processes of fermentation and putrefaction, that every disturbance of the mutual attraction subsisting between the elements of a body gives rise to a transformation. The elements arrange themselves according to the degrees of their reciprocal attraction into new combinations, which are incapable of farther change under the same conditions.

The products of these transformations vary with their causes, that is, with the different conditions on which their production depended; and are as innumerable as these conditions themselves. The chemical character of an acid, for example, is its unceasing disposition to saturation by means of a base; this disposition differs in intensity in different acids; but when it is satisfied, the acid character entirely disappears. The chemical character of a base is exactly the reverse of this, but both an acid and a base, notwithstanding the great difference in their properties, effect, in most cases, the same kind of transformations.

Hydrocyanic acid and water contain the elements of *carbonic acid, ammonia, urea, cyanuric acid, cyanilic acid, oxalic acid, formic acid, melam, ammelin, melamin, azulmin, mellon, hydromellonic acid, allantoin, &c.* It is well known, that all these very different substances can be obtained from hydrocyanic acid and the elements of water, by various chemical transformations.

The whole process of nutrition may be understood by the consideration of one of these transformations.

Hydrocyanic acid and water, for example, when brought into contact with muriatic acid, are decomposed into formic acid and ammonia; both of these products of decomposition contain the elements of hydrocyanic acid and water, although in another form, and arranged in a different order. The change results from the strong disposition or struggle of muriatic acid to undergo saturation, in consequence of which the hydrocyanic acid and water suffer mutual decomposition. The nitrogen of the hydrocyanic acid and the hydrogen of the water unite together and form a base, ammonia, with which the acid unites; the chemical characters of the acid being at the same time lost, because its desire for saturation is satisfied by its uniting with ammonia. Ammonia itself was not previously present, but only its elements, and the power to form it. The simultaneous decomposition of hydrocyanic acid and water in this instance does not take place in consequence of the chemical affinity of muriatic acid for ammonia, since hydrocyanic acid and water contain no ammonia. An affinity of one body for a second which is totally without the sphere of its attractions, or which, so far as it is concerned, does not exist, is quite inconceivable. The ammonia in this case is formed only on account of the existing attractive desire of the acid for saturation. Hence we may perceive how much these modes of decomposition, to which the name of *transformations* or *metamorphoses* has been especially applied, differ from the ordinary chemical decompositions.

In consequence of the formation of ammonia, the other elements of hydrocyanic acid, namely, carbon and hydrogen, unite with the oxygen of the decomposed water, and form *formic acid,* the elements of this substance with the power of combination being present. Formic acid here represents the excrementitious matters; ammonia, the new substance, assimilated by an organ of a plant or animal.

Each organ extracts from the food presented to it what it requires for its own sustenance; while the remaining elements, which are not assimilated, combine together and are separated as excrement. The excrementitious matters of one organ come in contact with another during their passage through the organism, and in consequence suffer new transformations; the useless matters rejected by one organ containing the elements for the nutrition of a second and a third organ: but at last, being capable of no farther transformations, they are separated from the system by the organs destined for that purpose. Each part of an organized being is fitted for its peculiar functions. A cubic inch of sulphuretted hydrogen introduced into the lungs would cause instant death, but it is formed, under a variety of circumstances, in the intestinal canal without any injurious effect.

In consequence of such transformations as we have described, excrements are formed of various composition, some of these contain carbon in excess, others nitrogen, and others again hydrogen and oxygen. The kidneys, liver, and lungs, are organs of excretion; the first separate from the body all those substances in which a large proportion of nitrogen is contained; the second, those with an excess of carbon; and the third, such as are composed principally of oxygen and hydrogen. Alcohol, also, and the volatile oils which are incapable of being assimilated, are exhaled through the lungs, and not through the skin.

Respiration must be regarded as a slow process of combustion or constant decomposition. If it be subject to the laws which regulate the processes of decomposition generally, the oxygen of the inspired air cannot combine directly with the carbon of compounds of that element contained in the blood; the hydrogen only can combine with the oxygen of the air, or undergo a higher degree of oxidation. Oxygen is absorbed without uniting with carbon; and carbonic acid is disengaged, the carbon and oxygen of which must be derived from matters previously existing in the blood.*

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* Teltow is a village near Berlin, where small parsneps are cultivated in a sandy soil; they are much esteemed, and weigh rarely above one ounce.

* The examination of the air expired by consumptive persons, as well as of their blood, would doubtless throw much light on the nature of *phthisis pulmonaris.* Considered in a chemical point of view, the decomposition of the blood, as it takes place in the lungs, is a true process of putrefaction. (See Part II.) The lungs are also the seat of the transformation of the various substances contained in the blood. It certainly well merits

All superabundant nitrogen is eliminated from the body, as a liquid excrement, through the urinary passages; all solid substances, incapable of farther transformation, pass out by the intestinal canal, and all gaseous matter by the lungs.

We should not permit ourselves to be withheld by the idea of a *vital principle*, from considering in a chemical point of view the process of the transformation of the food, and its assimilation by the various organs. This is the more necessary, as the views, hitherto held, have produced no results, and are quite incapable of useful application.

Is it truly vitality, which generates sugar in the germ for the nutrition of young plants, or which gives to the stomach the power to dissolve, and to prepare for assimilation, all the matter introduced into it? A decoction of malt possesses as little power to reproduce itself, as the stomach of a dead calf; both are, unquestionably, destitute of life. But when amylin or starch is introduced into a decoction of malt, it changes, first into a gummy-like matter, and lastly into sugar. Hard-boiled albumen and muscular fibre can be dissolved in a decoction of a calf's stomach, to which a few drops of muriatic acid have been added, precisely as in the stomach itself.* (Schwann, Schulz.)

The power, therefore, to effect transformations, does not belong to the vital principle: each transformation is owing to a disturbance in the attraction of the elements of a compound, and is consequently a purely chemical process. There is no doubt that this process takes place in another form from that of the ordinary decomposition of salts, oxides, or sulphurets. But is it the fault of chemistry that physiology has hitherto taken no notice of this new form of chemical action?

Physicians are accustomed to administer whole ounces of borax to patients suffering under urinary calculi, when it is known that the bases of all alkaline salts formed by organic acids are carried through the urinary passages in the form of alkaline carbonates, capable of dissolving calculi (Wöhler.) Is this rational? The medical reports state, that upon the Rhine, where so much cream of tartar is consumed in wine, the only cases of calculous disorders are those which are imported from other districts. We know that the uric acid calculus is transformed into the mulberry calculus (which contains oxalic acid,) when patients suffering under the former exchange the town for the country, where less animal and more vegetable food is used. Are all these circumstances incapable of explanation?

The volatile oil of the roots of valerian may be obtained from the oil generated during the fermentation of potatoes (Dumas,) and the oil of the *Spiræa ulmaria* from the crystalline matter of the bark of the willow (Piria.) We are able to form in our laboratories formic acid, oxalic acid, urea, and the crystalline substances existing in the liquid of the allantois of the cow, all products, it is said, of the vital principle. We see, therefore, that this mysterious principle has many relations in common with chemical forces, and that the latter can indeed replace it. What these relations are, it remains for physiologists to investigate. Truly it would be extraordinary if this vital principle, which uses every thing for its own purposes, had alloted no share to chemical forces, which stand so freely at its disposal. We shall obtain that which is obtainable in a rational inquiry into nature, if we separate the actions belonging to chemical powers from those which are subordinate to other influences. But the expression "vital principle" must in the mean time be considered as of equal value with the terms *specific* or *dynamic* in medicine: every thing is specific which we cannot explain, and dynamic is the explanation of all which we do not understand; the terms having been invented merely for the purpose of concealing ignorance by the application of learned epithets.

Transformations of existing compounds are constantly taking place during the whole life of a plant, in consequence of which, and as the results of these transformations, there are produced gaseous matters which are excreted by the leaves and blossoms, solid excrements deposited in the bark, and fluid soluble substances which are eliminated by the roots. Such secretions are most abundant immediately before the formation and during the continuance of the blossoms; they diminish after the development of the fruit. Substances containing a large proportion of carbon are excreted by the roots and absorbed by the soil. Through the expulsion of these matters unfitted for nutrition, the soil receives again with usury, the carbon which it had at first yielded to the young plants as food, in the form of carbonic acid.

The soluble matter thus acquired by the soil is still capable of decay and putrefaction, and by undergoing these processes furnishes renewed sources of nutrition to another generation of plants; it becomes *humus*. The cultivated soil is thus placed in a situation exactly analogous to that of forests and meadows, for the leaves of trees which fall in the forest in autumn, and the old roots of grass in the meadow, are likewise converted into humus by the same influence: a soil receives more carbon in this form than its decaying humus had lost as carbonic acid.

Plants do not exhaust the carbon of a soil in the normal condition of their growth; on the contrary, they add to its quantity. But if it is true that plants give back more carbon to a soil than they take from it, it is evident that their growth must depend upon the reception of nourishment from the atmosphere in the form of carbonic acid. The influence of humus upon vegetation is explained by the foregoing facts in the most clear and satisfactory manner.

Humus does not nourish plants by being taken up and assimilated in its unaltered state, but by presenting a slow and lasting source of carbonic acid, which is absorbed by the roots, and is the principal nutriment of young plants at a time when, being destitute of leaves, they are unable to extract food from the atmosphere.

In former periods of the earth's history, its surface was covered with plants, the remains of which are still found in the coal formations. These plants—the gigantic monocotyledons, ferns, palms, and reeds—belong to a class to which nature has given the power, by means of an immense extension of their leaves, to dispense with nourishment from the soil. They resemble in this respect the plants which we raise from bulbs and tubers, and which live while young upon the substances contained in their seed, and require no food from the soil when their exterior organs of nutrition are formed. This class of plants is even at present ranked amongst those which do not exhaust the soil.

The necessity of the existence of plants such as these at the commencement of vegetation, must now be apparent. Humus is a product of the decay of vegetable matter, and therefore could not have existed to supply the first plants with the food necessary for the development of the more delicate kinds. Hence the plants capable of flourishing under such circumstances could only be those which receive their nourishment from the air alone. By their decay, however, the soil in which they grew became supplied with vegetable matter, and the progress of vegetation must have furnished to the earth materials adapted for the development of those plants, which depend upon the nutriment contained in the soil, until those organs are formed which are destined for the assumption of nourishment from the atmosphere.

The plants of every former period are distinguished from those of the present by the inconsiderable development of their roots. Fruit, leaves, seeds, nearly every part of the plants of a former world, except the roots, are found in the brown coal formation. The vascular bundles, and the perishable cellular tissue, of which their roots consisted, have been the first to suffer decomposition. But when we examine oaks and other trees, which in consequence of revolutions of the same kind occurring in later ages have undergone the same changes, we never find their roots absent.

The verdant plants of warm climates are very often such as obtain from the soil only a point of attachment, and are not dependent on it for their growth. How extremely small are the roots of the *Cactus*, *Sedum*, and *Sempervivum*, in proportion to their mass, and to the surface of their leaves! Large forests are often found growing in soils absolutely destitute of carbonaceous matter; and the extensive prairies of the western continent show that the carbon necessary for the sustenance of a plant may be entirely extracted from the atmosphere. Again, in the most dry and barren sand, where it is impossible for nourishment to be obtained through the roots, we see the milky-juiced plants attain complete perfection. The moisture necessary for the nutrition of these plants is derived from the atmosphere, and when assimilated is secured from evaporation by the nature of the juice itself. Caoutchouc and wax, which are formed in these plants, surround the water, as in oily emulsions, with an impenetrable envelope by which the fluid is retained, in the same manner as milk is prevented from evaporating by the skin which forms upon it. These plants, therefore, become turgid with their juices.

Particular examples might be cited of plants, which have been brought to maturity, upon a small scale, without the assistance of mould; but fresh proofs of the accuracy of our theory respecting the origin of carbon would be superfluous and useless, and could not render more striking, or more convincing, the arguments already adduced. It must not, however, be left unmentioned, that common wood charcoal, by virtue merely of its ordinary well-known properties, can completely replace vegetable mould or *humus*. The experiments of Lukas, which are appended to this work, spare me all further remarks upon its efficacy.

Plants thrive in powdered charcoal, and may be brought to blossom and bear fruit if exposed to the influence of the rain and the atmosphere; the charcoal may be previously heated to redness. Charcoal is the most "indifferent" and most unchangeable substance known; it may be kept for centuries without change, and is, therefore, not subject to decomposition. The only substances which it can yield to plants are some salts, which it contains, amongst which is silicate of potash. It is known, however, to possess the power of condensing gases within its pores, and particularly carbonic acid. And it is by virtue of this power that the roots of plants are supplied in charcoal, exactly as in humus, with an atmosphere of carbonic acid and air, which is renewed as quickly as it is abstracted.

In charcoal powder, which had been used for this purpose by Lukas for several years,

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consideration, that the most approved remedies for counteracting or stopping the progress of this frightful malady are precisely those which are found most efficacious in retarding putrefaction. Thus, it is well known that much relief is afforded by a residence in works in which empyreumatic oils are manufactured by dry distillation, such as manufactories for the preparation of gas or sal-ammoniac. For the same reason, the respiration of wood vinegar (pyroligneous acid,) of chlorine, and certain of the acids, has been recognized as a means of alleviating the disease.

* This remarkable action has been completely confirmed in this laboratory (Giessen,) by Dr. Vogel, a highly distinguished young physiologist.

Buchner found a brown substance soluble in alkalies. This substance was evidently due to the secretions from the roots of the plants which grew in it.

A plant placed in a closed vessel in which the air, and therefore the carbonic acid, cannot be renewed, dies exactly as it would do in the vacuum of an air-pump, or in an atmosphere of nitrogen or carbonic acid, even though its roots be fixed in the richest mould.

Plants do not, however, attain maturity, under ordinary circumstances, in charcoal powder, when they are moistened with pure distilled water instead of rain or river water. Rain water must, therefore, contain within it one of the essentials of vegetable life; and it will be shown, that this is the presence of a compound containing nitrogen, the exclusion of which entirely deprives humus and charcoal of their influence upon vegetation.

CHAPTER IV.

ON THE ASSIMILATION OF HYDROGEN.

The atmosphere contains the principal food of plants in the form of carbonic acid, in the state, therefore, of an oxide. The solid part of plants (woody fibre) contains carbon and the constituents of water, or the elements of carbonic acid, together with a certain quantity of hydrogen. It has formerly been mentioned that water consists of the two gases, oxygen and hydrogen. The range of affinity possessed by both these elements is so extensive that numerous causes occur which effect the decomposition of water. Indeed, there is no compound which plays a more general or more important part in the phenomena of combination and decomposition. We can conceive the wood to arise from a combination of the carbon of the carbonic acid with the elements of water, under the influence of solar light. In this case, 72.35 parts of oxygen, by weight, must be separated as a gas for every 27.65 parts of carbon, which are assimilated by a plant; for this is the composition of carbonic acid in 100 parts. Or, what is much more probable, plants, under the same circumstances, may decompose water, the hydrogen of which is assimilated along with carbonic acid, whilst its oxygen is separated. If the latter change takes place, 8.04 parts of hydrogen must unite with 100 parts of carbonic acid, in order to form woody fibre, and the 72.35 parts by weight of oxygen, which was in combination with the hydrogen of the water, and which exactly corresponds in quantity with the oxygen contained in the carbonic acid, must be separated in a gaseous form.

Each acre of land, which produces 10 cwts. of carbon, gives annually to the atmosphere 865 lbs. of free oxygen gas. The specific weight of oxygen is expressed by the number 1.1026; hence 1 cubic metre of oxygen weighs 3.157 lbs., and 2865 lbs. of oxygen correspond to 908 cubic metres, or 32,007 cubic feet.

An acre of meadow, wood, or cultivated land in general replaces, therefore, in the atmosphere as much oxygen as is exhausted by 10 cwts. of carbon, either in its ordinary combustion in the air or in the respiratory process of animals.

It has been mentioned at a former page that pure woody fibre contains carbon and the component parts of water, but that ordinary wood contains more hydrogen than corresponds to this proportion. This excess is owing to the presence of the green principle of the leaf, wax, resin, and other bodies rich in hydrogen. Water must be decomposed, in order to furnish the excess of this element, and consequently one equivalent of oxygen must be given back to the atmosphere for every equivalent of hydrogen appropriated by a plant to the production of those substances. The quantity of oxygen thus set at liberty cannot be insignificant, for the atmosphere must receive 989 cubic feet of oxygen for every pound of hydrogen assimilated.

It has already been stated, that a plant, in the formation of woody fibre, must always yield to the atmosphere the same proportional quantity of oxygen; that the volume of this gas set free would be the same whether it were due to the decomposition of carbonic acid or of water. A little consideration will show that this must be the case. It has repeatedly been stated, that woody fibre contains carbon in combination with oxygen and hydrogen in the same proportion in which they exist in water. Water contains 1 equivalent of each element, whilst carbonic acid consists of 1 equivalent of carbon, united to 2 equivalents of oxygen. In the formation of woody fibre, 2 equivalents of oxygen must therefore be liberated. The woody fibre can only be formed in one of two ways: either the carbon of carbonic acid unites directly with water, or the hydrogen of water combines with the oxygen of the carbonic acid. In the former of these cases, the two equivalents of oxygen in the carbonic acid must be liberated; in the latter, two atoms of water must be decomposed, the hydrogen of which unites with the oxygen of the carbonic acid, whilst the oxygen of the water, thus set free, is disengaged in the state of a gas. It was considered most probable that the latter was the case.

From their generating caoutchouc, wax, fats, and volatile oils containing hydrogen in large quantity, and no oxygen, we may be certain that plants possess the property of decomposing water, because from no other body could they obtain the hydrogen of those matters. It has also been proved by the observations of Humboldt on the fungi, that water may be decomposed without the assimilation of hydrogen. Water is a remarkable combination of two elements,

which have the power to separate themselves from one another, in innumerable processes, in a manner imperceptible to our senses; while carbonic acid, on the contrary, is only decomposable by violent chemical action.

Most vegetable structures contain hydrogen in the form of water, which can be separated as such, and replaced by other bodies; but the hydrogen which is essential to their constitution cannot possibly exist in the state of water.

All the hydrogen necessary for the formation of an organic compound is supplied to a plant by the decomposition of water. The process of assimilation, in its most simple form, consists in the extraction of hydrogen from water, and carbon from carbonic acid, in consequence of which, either all the oxygen of the water and carbonic acid is separated, as in the formation of caoutchouc, the volatile oils which contain no oxygen, and other similar substances, or only a part of it is exhaled.

The known composition of the organic compounds most generally present in vegetables, enables us to state in definite proportions the quantity of oxygen separated during their formation.

36 eq. carbonic acid and
22 eq. hydrogen derived } = *Woody Fibre,*
from 22 eq. water.
with the separation of 72 eq. oxygen.
36 eq. carbonic acid and
36 eq. hydrogen derived } = *Sugar,*
from 36 eq. water
with the separation of 72 eq. oxygen.
36 eq. carbonic acid and
30 eq. hydrogen derived } = *Starch,*
from 30 eq. water
with the separation of 72 eq. oxygen.
36 eq. carbonic acid and
16 eq. hydrogen derived } = *Tannic Acid,*
from 16 eq. water
with the separation of 64 eq. oxygen.
36 eq. carbonic acid and
18 eq. hydrogen derived } = *Tartaric Acid,*
from 18 eq. water
with the separation of 45 eq. oxygen.
36 eq. carbonic acid and
18 eq. hydrogen derived } = *Malic Acid,*
from 18 eq. water
with the separation of 54 eq. oxygen.
36 eq. carbonic acid and
24 eq. hydrogen derived } = *Oil of Turpentine.*
from 24 eq. water
with the separation of 84 eq. oxygen.

It will readily be perceived that the formation of the acids is accompanied with the smallest separation of oxygen; that the amount of oxygen set free increases with the production of the so-named neutral substances, and reaches its maximum in the formation of the oils. Fruits remain acid in cold summers; while the most numerous trees under the tropics are those which produce oils, caoutchouc, and other substances containing very little oxygen. The action of sunshine and influence of heat upon the ripening of fruit is thus, in a certain measure, represented by the numbers above cited

The green resinous principle of the leaf diminishes in quantity, while oxygen is absorbed, when fruits are ripened in the dark; red and yellow colouring matters are formed; tartaric, citric, and tannic acids disappear, and are replaced by sugar, amylin, or gum. 6 eq. *Tartaric Acid*, by absorbing 6 eq. oxygen from the air, form *Grape Sugar*, with the separation of 12 eq. carbonic acid. 1 eq. *Tannic Acid*, by absorbing 8 eq. oxygen from the air, and 4 eq. water, form 1 eq. of *Amylin*, or starch, with separation of 6 eq. carbonic acid.

We can explain, in a similar manner, the formation of all the component substances of plants which contain no nitrogen, whether they are produced from carbonic acid and water, with separation of oxygen, or by the conversion of one substance into the other, by the assimilation of oxygen and separation of carbonic acid. We do not know in what form the production of these constituents takes place; in this respect, the representation of their formation which we have given must not be received in an absolute sense, it being intended only to render the nature of the process more capable of apprehension; but it must not be forgotten, that if the conversion of tartaric acid into sugar, in grapes, be considered as a fact, it must take place under all circumstances in the same proportions.

The vital process in plants is, with reference to the point we have been considering, the very reverse of the chemical processes engaged in the formation of salts. Carbonic acid, zinc, and water, when brought into contact, act upon one another, and *hydrogen is separated*, while a white pulverulent compound is formed, which contains carbonic acid, zinc, and the oxygen of the water. A living plant represents the zinc in this process: but the process of assimilation gives rise to compounds, which contain the elements of carbonic acid and the hydrogen of water, whilst *oxygen is separated.*

Decay has been described above as the great operation of nature, by which that oxygen, which was assimilated by plants during life, is again returned to the atmosphere. During the progress of growth, plants appropriate carbon in the form of carbonic acid, and hydrogen from the decomposition of water, the oxygen of which is set free, together with a part of all that contained in the carbonic acid. In the process of putrefaction, a quantity of water, exactly corresponding to that of the hydrogen, is again formed by extraction of oxygen from the air; while all the oxygen of the organic matter is returned to the atmosphere in the form of carbonic acid. Vegetable matters can emit carbonic acid, during their decay, only in proportion to the quantity of oxygen which they contain; acids, therefore, yield more carbonic acid than neutral compounds; while fatty acids, resin, and wax, do not putrefy; they remain in the soil without any apparent change.

The numerous springs which emit carbonic acid in the neighbourhood of extinct volcanoes, must be regarded as another means of compensating for the carbonic acid absorbed and retained by plants during life, and consequently as a source by which oxygen is supplied to the atmosphere. Bischof calculated that the springs of carbonic acid in the *Eifel* (a volcanic district near Coblenz) send into the air every day more than 110,000 lbs. of carbonic acid, corresponding to 79,000 lbs. of pure oxygen.

CHAPTER V.

ON THE ORIGIN AND ASSIMILATION OF NITROGEN.

We cannot suppose that a plant could attain maturity, even in the richest vegetable mould, without the presence of matter containing nitrogen; since we know that nitrogen exists in every part of the vegetable structure. The first and most important question to be solved, therefore, is: How and in what form does nature furnish nitrogen to vegetable albumen, and gluten, to fruits and seeds?

This question is susceptible of a very simple solution.

Plants, as we know, grow perfectly well in pure charcoal, if supplied at the same time with rain water. Rain water can contain nitrogen only in two forms, either as dissolved atmospheric air, or as ammonia, which consists of this element and hydrogen. Now, the nitrogen of the air cannot be made to enter into combination with any element except oxygen, even by the employment of the most powerful chemical means. We have not the slightest reason for believing that the nitrogen of the atmosphere takes part in the processes of assimilation of plants and animals; on the contrary, we know that many plants emit the nitrogen which is absorbed by their roots, either in the gaseous form, or in solution in water. But there are on the other hand numerous facts, showing, that the formation in plants of substances containing nitrogen, such as gluten, takes place in proportion to the quantity of this element which is conveyed to their roots in the state of ammonia, derived from the putrefaction of animal matter.

Ammonia, too, is capable of undergoing such a multitude of transformations, when in contact with other bodies, that in this respect it is not inferior to water, which possesses the same property in an eminent degree. It possesses properties which we do not find in any other compound of nitrogen: when pure, it is extremely soluble in water; it forms soluble compounds with all the acids; and when in contact with certain other substances, it completely resigns its character as an alkali, and is capable of assuming the most various and opposite forms Formate of ammonia changes, under the influence of a high temperature, into hydrocyanic acid and water, without the separation of any of its elements. Ammonia forms urea, with cyanic acid, and a series of crystalline compounds, with the volatile oils of mustard and bitter almonds. It changes into splendid blue or red colouring matters, when in contact with the bitter constituent of the bark of the apple-tree (*phloridzin,*) with the sweet principle of the *Variolaria dealbata* (*orcin,*) or with the tasteless matter of the *Rocella tinctoria* (*erythrin.*) All blue colouring matters which are reddened by acids, and all red colouring substances which are rendered blue by alkalies, contain nitrogen, but not in the form of a base.

These facts are not sufficient to establish the opinion that it is ammonia which affords all vegetables, without exception, the nitrogen which enters into the composition of their constituent substances. Considerations of another kind, however, give to this opinion a degree of certainty which completely excludes all other views of the matter.

Let us picture to ourselves the condition of a well-cultured farm, so large as to be independent of assistance from other quarters. On this extent of land there is a certain quantity of nitrogen contained both in the corn and fruit which it produces, and in the men and animals which feed upon them, and also in their excrements. We shall suppose this quantity to be known. The land is cultivated without the importation of any foreign substance containing nitrogen. Now, the products of this farm must be exchanged every year for money, and other necessaries of life—for bodies, therefore, which contain no nitrogen. A certain proportion of nitrogen is exported with corn and cattle; and this exportation takes place every year, without the smallest compensation; yet after a given number of years, the quantity of nitrogen will be found to have increased. Whence, we may ask, comes this increase of nitrogen? The nitrogen in the excrements cannot reproduce itself, and the earth cannot yield it. Plants, and consequently animals, must, therefore, derive their nitrogen from the atmosphere.

It will in a subsequent part of this work be shown that the last products of the decay and putrefaction of animal bodies present themselves in two different forms. They are in the form of a combination of hydrogen and nitrogen—*ammonia*—in the temperate and cold climates, and in that of a compound containing oxygen—*nitric acid*—in the tropics and hot climates. The formation of the latter is preceded by the production of the first. Ammonia is the last product of the putrefaction of animal bodies; nitric acid is the product of the transformation of ammonia. A generation of a thousand million men is renewed every thirty years: thousands of millions of animals cease to live and are reproduced, in a much shorter period. Where is the nitrogen which they contained during life? There is no question which can be answered with more positive certainty. All animal bodies during their decay yield the nitrogen which they contain to the atmosphere, in the form of ammonia. Even in the bodies buried sixty feet under ground in the churchyard of the Eglise des Innocens, at Paris, all the nitrogen contained in the adipocire was in the state of ammonia. Ammonia is the simplest of all the compounds of nitrogen; and hydrogen is the element for which nitrogen possesses the most powerful affinity.

The nitrogen of putrified animals is contained in the atmosphere as ammonia, in the form of a gas which is capable of entering into combination with carbonic acid and of forming a volatile salt. Ammonia in its gaseous form, as well as all its volatile compounds, is of extreme solubility in water. Ammonia, therefore, cannot remain long in the atmosphere, as every shower of rain must condense it, and convey it to the surface of the earth. Hence, also, rain-water must at all times contain ammonia, though not always in equal quantity. It must be greater in summer than in spring or in winter, because the intervals of time between the showers are in summer greater; and when several wet days occur, the rain of the first must contain more of it than that of the second. The rain of a thunder storm, after a long-protracted drought, ought for this reason to contain the greatest quantity which is conveyed to the earth at one time.

But we have formerly stated, that all the analyses of atmospheric air hitherto made have failed to demonstrate the presence of ammonia, although, according to our view, it can never be absent. Is it possible that it could have escaped our most delicate and most exact apparatus? The quantity of nitrogen contained in a cubic foot of air is certainly extremely small, but, notwithstanding this, the sum of the quantities of nitrogen from thousands and millions of dead animals is more than sufficient to supply all those living at one time with this element.

From the tension of aqueous vapour at 15° C. (59° F.)=6,98 lines (Paris measure,) and from its known specific gravity at 0° C. (32° F.,) it follows that when the temperature of the air is 59° F. and the height of the barometer 28″, 1 cubic metre or 35.3 cubic feet of aqueous vapour are contained in 487 cubic metres, or 17,191 cubic feet of air: 35.3 cubic feet of aqueous vapour weigh about 1½ lb. Consequently, if we suppose that the air saturated with moisture at 59° F. allows all the water which it contains in the gaseous form to fall as rain, then 1.1 pound of rain-water must be obtained from every 11,471 cubic feet of air. The whole quantity of ammonia contained in the same number of cubic feet will also be returned to the earth in this one pound of rain-water. But if the 11,471 cubic feet of air contain a single grain of ammonia, then ten cubic inches—the quantity usually employed in an analysis—must contain only 0.000000048 of a grain. This extremely small proportion is absolutely inappreciable by the most delicate and best eudiometer; it might be classed among the errors of observation, even were its quantity ten thousand times greater. But the detection of ammonia must be much more easy when a pound of rain-water is examined, for this contains all the gas that was diffused through 11,471 cubic feet of air.

If a pound of rain-water contain only ¼th of a grain of ammonia, then a field of 26,910 square feet must receive annually upwards of 88 lbs. of ammonia, or 71 lbs. of nitrogen; for by the observations of Schubler, which were formerly alluded to, about 770,000 lbs. of rain fall over this surface in four months, and consequently the annual fall must be 2,310,000 lbs. This is much more nitrogen than is contained in the form of vegetable albumen and gluten, in 2920 lbs. of wood, 3085 lbs. of hay, or 200 cwt. of beet-root, which are the yearly produce of such a field; but it is less than the straw, roots, and grain of corn, which might grow on the same surface, would contain.*

Experiments made in this laboratory (Giessen) with the greatest care and exactness have placed the presence of ammonia in rain-water beyond all doubt. It has hitherto escaped observation, because no person thought of searching for it. All the rain-water employed in this inquiry was collected 600 paces south-west of Giessen, whilst the wind was blowing in the direction of the town. When several hundred pounds of it were distilled in a copper still, and the first two or three pounds evaporated with the addition of a little muriatic acid, a very distinct crystallisation of sal-ammoniac was obtained: the crystals had always a brown or yellow colour.

Ammonia may likewise be always detected in snow-water. Crystals of sal-ammoniac were obtained by evaporating in a vessel with muriatic acid several pounds of snow, which were gathered from the surface of the ground in March, when the snow had a depth of 10 inches. Ammonia was set free from these crystals by the addition of hydrate of lime. The inferior layers of snow which rested upon the ground contained a quantity decidedly greater than those which formed the surface.

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* The advocates of the importance of humus as a nourishment for plants, being driven from their position by the facts brought forward in the preceding chapters, have found in the ammonia of the atmosphere an explanation of the manner in which humus acquires its solubility, and therefore its capability of being assimilated by plants. Now, it is very true that humic acid is soluble in ammonia; but the humic acid of chemists *is not contained in soils.* Were it so, on treating mould with water we should obtain a dark-coloured solution of humate of ammonia. But we obtain a solution which is entirely devoid of this acid. It cannot be too distinctly kept in mind that *humic acid* is the product of the decomposition of *humus* by means of caustic alkalies. Again, if the coloured solutions of humates of ammonia, lime, or magnesia, be poured upon good mould or decayed oak-wood (which is nearly pure *humus*,) and allowed to filter, the solutions are observed to pass through quite colourless; they are decolourised just as if they had been filtered through charcoal. Here, then, *humus* possesses the property of extracting *humic acid* from water; or, in other words, soils have the power of rendering humic acid insoluble, or unfit for assimilation.—Ed.

It is worthy of observation that the ammonia contained in rain and snow water possesses an offensive smell of perspiration and animal excrements,—a fact which leaves no doubt respecting its origin.

Hünefield has proved that all the springs in Greifswalde, Wick, Eldena, and Kostenhagen, contain carbonate and nitrate of ammonia. Ammoniacal salts have been discovered in many mineral springs in Kissingen and other places. The ammonia of these salts can only arise from the atmosphere.

Any one may satisfy himself of the presence of ammonia in rain by simply adding a little sulphuric or muriatic acid to a quantity of rain-water, and evaporating this nearly to dryness in a clean porcelain basin. The ammonia remains in the residue, in combination with the acid employed; and may be detected either by the addition of a little chloride of platinum, or more simply by a little powdered lime, which separates the ammonia, and thus renders its peculiar pungent smell sensible.* The sensation which is perceived upon moistening the hand with rain-water, so different from that produced by pure distilled water, and to which the term *softness* is vulgarly applied, is also due to the carbonate of ammonia contained in the former.

The ammonia which is removed from the atmosphere by rain and other causes, is as constantly replaced by the putrefaction of animal and vegetable matters. A certain portion of that which falls with the rain evaporates again with the water, but another portion is, we suppose, taken up by the roots of plants, and entering into new combinations in the different organs of assimilation, produces albumen, gluten, quinine, morphia, cyanogen, and a number of other compounds containing nitrogen. The chemical characters of ammonia render it capable of entering into such combinations, and of undergoing numerous transformations. We have now only to consider whether it really is taken up in the form of ammonia by the roots of plants, and in that form applied by their organs to the production of the azotised matters contained in them. This question is susceptible of easy solution by well-known facts.

In the year 1834, I was engaged with Dr. Wilbrand, professor of botany in the university of Giessen, in an investigation respecting the quantity of sugar contained in different varieties of maple-trees, which grew upon soils which were not manured. We obtained crystallised sugars from all, by simply evaporating their juices, without the addition of any foreign substance; and we unexpectedly made the observation, that a great quantity of ammonia was emitted from this juice when mixed with lime, and also from the sugar itself during its refinement. The vessels which hung upon the trees in order to collect the juice were watched with greater attention, on account of the suspicion that some evil-disposed persons had introduced urine into them, but still a large quantity of ammonia was again found in the form of neutral salts. The juice had no colour, and had no reaction on that of vegetables. Similar observations were made upon the juice of the birch tree; the specimens subjected to experiment were taken from a wood several miles distant from any house, and yet the clarified juice, evaporated with lime, emitted a strong odour of ammonia.

In the manufactories of beet-root sugar, many thousand cubic feet of juice are daily purified with lime, in order to free it from vegetable albumen and gluten, and it is afterwards evaporated for crystallisation. Every person who has entered such a manufactory must have been astonished at the great quantity of ammonia which is volatilised along with the steam. This ammonia must be contained in the form of an ammoniacal salt, because the neutral juice possesses the same characters as the solution of such a salt in water; it acquires, namely, an acid reaction during evaporation, in consequence of the neutral salt being converted by loss of ammonia into an acid salt. The free acid which is thus formed is a source of loss to the manufacturers of sugar from beet-root, by changing a part of the sugar into uncrystallisable grape sugar and syrup.

The products of the distillation of flowers, herbs, and roots, with water, and all extracts of plants made for medicinal purposes, contain ammonia. The unripe, the transparent, and gelatinous pulp of the almond and peach emit much ammonia when treated with alkalies. (Robiquet.) The juice of the fresh tobacco leaf contains ammoniacal salts. The water which exudes from a cut vine, when evaporated with a few drops of muriatic acid, also yields a gummy deliquescent mass, which evolves much ammonia on the addition of lime. Ammonia exisst in every part of plants, in the roots (as in

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* Since the appearance of the last edition, this experiment has been repeated by many in France, Germany, America, and England, and the existence of ammonia in the atmosphere has been completely confirmed. The assertion that this ammonia possesses the "offensive smell of perspiration and animal excrements," has been ridiculed by many as fanciful—by none, however, who have made the experiment. The experiment is so exceedingly easy to perform, that any one may convince himself of the accuracy of the statement.—Ed.

beet-root,) in the stem (of the maple-tree,) and in all blossoms and fruit in an unripe condition.

The juices of the maple and birch contain both sugar and ammonia, and therefore afford all the conditions necessary for the formation of the azotised components of the branches, blossoms, and leaves, as well as of those which contain no azote or nitrogen. In proportion as the developement of those parts advances, the ammonia diminishes in quantity, and when they are fully formed, the tree yields no more juice.

The employment of animal manure in the cultivation of grain, and the vegetables which serve for fodder to cattle, is the most convincing proof that the nitrogen of vegetables is derived from ammonia. The quantity of gluten in wheat, rye, and barley, is very different; these kinds of grain also, even when ripe, contain this compound of nitrogen in very different proportions. Proust found French wheat to contain 12.5 per cent. of gluten; Vogel found that the Bavarian contained 24 per cent.; Davy obtained 19 per cent. from winter, and 24 from summer wheat; from Sicilian 21, and from Barbary wheat 19 per cent. The meal of Alsace wheat contains, according to Boussingault, 17.3 per cent. of gluten; that of wheat grown in the "Jardin des Plantes" 26.7, and that of winter wheat 3.33 per cent. Such great differences must be owing to some cause, and this we find in the different methods of cultivation. An increase of animal manure gives rise not only to an increase in the number of seeds, but also to a most remarkable difference in the proportion of the substances containing nitrogen, such as the gluten which they contain.

Animal manure, in as far as regards the assimilation of nitrogen, acts only by the formation of ammonia. One hundred parts of wheat grown on a soil manured with cow-dung (a manure containing the smallest quantity of nitrogen,) afforded only 11.95 parts of gluten, and 64.34 parts of amylin, or starch; whilst the same quantity, grown on a soil manured with human urine, yielded the maximum of gluten, namely 35.1 per cent. Putrefied urine contains nitrogen in the forms of carbonate, phosphate, and lactate of ammonia, and in no other form than that of ammoniacal salts.

"Putrid urine is employed in Flanders as a manure with the best results. During the putrefaction of urine, ammoniacal salts are formed in large quantity, it may be said exclusively; for under the influence of heat and moisture, urea, the most prominent ingredient of the urine, is converted into carbonate of ammonia. The barren soil on the coast of Peru is rendered fertile by means of a manure called *Guano*, which is collected from several islands in the South Sea.* It is sufficient to add a small quantity of guano to a soil, which consists only of sand and clay, in order to procure the richest crop of maize. The soil itself does not contain the smallest particle of organic matter, and the manure employed is formed only of *urate*, *phosphate*, *oxalate*, and *carbonate of ammonia*, together with a few earthy salts."*

Ammonia, therefore, must have yielded the nitrogen to these plants. Gluten is obtained not only from corn, but also from grapes and other plants; but that extracted from the grapes is called vegetable albumen, although it is identical in composition and properties with the ordinary gluten.

It is ammonia which yields nitrogen to the vegetable albumen, the principal constituent of plants; and it must be ammonia which forms the red and blue colouring matters of flowers. Nitrogen is not presented to wild plants in any other form capable of assimilation. Ammonia, by its transformation, furnishes nitric acid to the tobacco plant, sun-flower, *Chenopodium*, and *Borago officinalis*, when they grow in a soil completely free from nitre. Nitrates are necessary constituents of these plants, which thrive only when ammonia is present in large quantity, and when they are also subject to the influence of the direct rays of the sun, an influence necessary to effect the disengagement within their stem and leaves of the oxygen, which shall unite with the ammonia to form nitric acid.

The urine of men and of carnivorous animals contains a large quantity of nitrogen, partly in the form of phosphates, partly as urea. Urea is converted during putrefaction into carbonate of ammonia, that is to say, it takes the form of the very salt which occurs in rain-water. Human urine is the most powerful manure for all vegetables containing nitrogen; that of horses and horned cattle contains less of this element, but infinitely more than the solid excrements of these animals. In addition to urea, the urine of herbivorous animals contains hippuric acid which is decomposed during putrefaction into benzoic acid and ammonia. The latter enters into the composition of the gluten, but the benzoic acid often remains unchanged: for example, in the *Anthoxanthum odoratum*.

The solid excrements of animals contain comparatively very little nitrogen, but this could not be otherwise. The food taken by animals supports them only in so far as it offers elements for assimilation to the various organs which they may require for their increase or renewal. Corn, grass, and all plants, without exception, contain azotised substances. The quantity of food which animals take for their nourishment, diminishes or increases in the same proportion as it contains more or less of the substances containing nitrogen. A horse may be kept alive by feeding it with potatoes, which contain a very small quantity of nitrogen; but life thus supported is a gradual starvation; the animal increases neither in size nor strength, and sinks under every exertion. The quantity of rice which an Indian eats astonishes the European; but the fact that rice contains less nitrogen than any other kind of grain at once explains the circumstance.

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* The guano, which forms a stratum several feet in thickness upon the surface of these islands, consists of the putrid excrements of innumerable sea fowl that remain on them during the breeding season. See the Chapter on Manures.)

* Boussingault, Ann. de Ch. et de Phys. lxv. p. 319.

Now, as it is evident that the nitrogen of the plants and seeds used by animals as food must be employed in the process of assimilation, it is natural to expect that the excrements of these animals will be deprived of it in proportion to the perfect digestion of the food, and can only contain it when mixed with secretions from the liver and intestines. Under all circumstances, they must contain less nitrogen than the food. When, therefore, a field is manured with animal excrements, a smaller quantity of matter containing nitrogen is added to it than has been taken from it in the form of grass, herbs, or seeds. By means of manure, an addition only is made to the nourishment which the air supplies.

In a scientific point of view, it should be the care of the agriculturist so to employ all the substances containing a large proportion of nitrogen which his farm affords in the form of animal excrements, that they shall serve as nutriment to his own plants. This will not be the case unless those substances are properly distributed upon his land. A heap of manure lying unemployed upon his land would serve him no more than his neighbours. The nitrogen in it would escape as carbonate of ammonia into the atmosphere, and a mere carbonaceous residue of decayed plants would, after some years, be found in its place.

All animal excrements emit carbonic acid and ammonia, as long as nitrogen exists in them. In every stage of their putrefaction an escape of ammonia from them may be induced by moistening them with a potash ley; the ammonia being apparent to the senses by a peculiar smell, and by the dense white vapour which arises when a solid body moistened with an acid is brought near it. This ammonia evolved from manure is imbibed by the soil either in solution in water, or in the gaseous form, and plants thus receive a larger supply of nitrogen than is afforded to them by the atmosphere.

But it is much less the quantity of ammonia, yielded to a soil by animal excrements, than the form in which it is presented by them, that causes their great influence on its fertility. Wild plants obtain more nitrogen from the atmosphere in the form of ammonia than they require for their growth, for the water which evaporates through their leaves and blossoms, emits, after some time, a putrid smell, a peculiarity possessed only by such bodies as contain nitrogen. Cultivated plants receive the same quantity of nitrogen from the atmosphere as trees, shrubs, and other wild plants; but this is not sufficient for the purposes of agriculture. Agriculture differs essentially from the cultivation of forests, inasmuch as its principal object consists in the production of nitrogen under any form capable of assimilation; whilst the object of forest culture is confined principally to the production of carbon. All the various means of culture are subservient to these two main purposes. A part only of the carbonate of ammonia which is conveyed by rain to the soil is received by plants, because a certain quantity of it is volatilised with the vapour of water; only that portion of it can be assimilated which sinks deeply into the soil, or which is conveyed directly to the leaves by dew, or is absorbed from the air along with the carbonic acid.

Liquid animal excrements, such as the urine with which the solid excrements are impregnated, contain the greatest part of their ammonia in the state of salts, in a form, therefore, in which it has completely lost its volatility; when presented in this condition, not the smallest portion of the ammonia is lost to the plants; it is all dissolved by water, and imbibed by their roots. The evident influence of gypsum upon the growth of grasses—the striking fertility and luxuriance of a meadow upon which it is strewed—depends only upon its fixing in the soil the ammonia of the atmosphere, which would otherwise be volatilized, with the water which evaporates.* The carbonate of ammonia contained in rain-water is decomposed by gypsum, in precisely the same manner as in the manufacture of sal-ammoniac. Soluble sulphate of ammonia and carbonate of lime are formed; and this salt of ammonia possessing no volatility is consequently retained in the soil. All the gypsum gradually disappears, but its action upon the carbonate of ammonia continues as long as a trace of it exists.

The beneficial influence of gypsum and of many other salts has been compared to that of aromatics, which increase the activity of the human stomach and intestines, and give a tone to the whole system. But plants contain no nerves; we know of no substance capable of exciting them to intoxication and madness, or of lulling them to sleep and repose. No substance can possibly cause their leaves to appropriate a greater quantity of carbon from the atmosphere, when the other constituents which the seeds, roots, and leaves require for their growth are wanting. The favourable action of small quantities of aromatics upon man, when mixed with his food, is undeniable; but aromatics are given to plants *without food* to be digested, and still they flourish with greater luxuriance.

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* It has long been the practice in some parts of the country to strew the floors of stables with gypsum. This prevents the disagreeable odour arising from the putrefaction of stable manure, by decomposing the ammoniacal salts which are formed.—Ed.

It is quite evident, therefore, that the common view concerning the influence of certain salts upon the growth of plants evinces only ignorance of its cause.

The action of gypsum or chloride of calcium really consists in their giving a fixed condition to the nitrogen—or ammonia which is brought into the soil, and which is indispensable for the nutrition of plants.

In order to form a conception of the effect of gypsum, it may be sufficient to remark that 110 lbs. of burned gypsum fixes as much ammonia in the soil as 6880 lbs. of horse's urine* would yield to it, even on the supposition that all the nitrogen of the urea and hippuric acid were absorbed by the plants without the smallest loss, in the form of carbonate of ammonia. If we admit with Boussingault† that the nitrogen in grass amounts to $\frac{1}{100}$ of its weight, then every pound of nitrogen which we add increases the produce of the meadow 100 lbs., and this increased produce of 100 lbs. is effected by the aid of a little more than 4 lbs. of gypsum.

Water is absolutely necessary to effect the decomposition of the gypsum, on account of its difficult solubility, (1 part of gypsum requires 400 parts of water for solution) and also to assist in the absorption of the sulphate of ammonia by the plants: hence it happens, that the influence of gypsum is not observable on dry fields and meadows. In such it would be advisable to employ a salt of more easy solubility, such as chloride of calcium.

The decomposition of gypsum by carbonate of ammonia does not take place instantaneously; on the contrary, it proceeds very gradually, and this explains why the action of the gypsum lasts for several years.

The advantage of manuring fields with burned clay, and the fertility of ferruginous soils, which have been considered as facts so incomprehensible, may be explained in an equally simple manner. They have been ascribed to the great attraction for water, exerted by dry clay and ferruginous earth; but common dry arable land possesses this property in as great a degree: and besides, what influence can be ascribed to a hundred pounds of water spread over an acre of land, in a condition in which it cannot be serviceable either by the roots or leaves? The true case is this:—

The oxides of iron and alumina are distinguished from all other metallic oxides by their power of forming solid compounds with ammonia. The precipitates obtained by the addition of ammonia to salts of alumina or iron are true salts, in which the ammonia is contained as a base. Minerals containing alumina or oxide of iron also possess, in an eminent degree, the remarkable property of attracting ammonia from the atmosphere and of retaining it. Vauquelin, whilst engaged in the trial of a criminal case, discovered that all rust of iron contains a certain quantity of ammonia. Chevalier afterwards found that ammonia is a constituent of all minerals containing iron; that even hematite, a mineral which is not at all porous, contains one per cent. of it. Bouis showed also, that the peculiar odour observed on moistening minerals containing alumina, is partly owing to their exhaling ammonia. Indeed, gypsum and some varieties of alumina, pipe-clay for example, emit so much ammonia, when moistened with caustic potash, that even after they had been exposed for two days, reddened litmus paper held over them becomes blue. Soils, therefore, which contain oxides of iron, and burned clay, must absorb ammonia, an action which is favoured by their porous condition; they further prevent the escape of the ammonia once absorbed by their chemical properties. Such soils, in fact, act precisely as a mineral acid would do, if extensively spread over their surface; with this difference, that the acid would penetrate the ground, enter into combination with lime, alumina, and other bases, and thus lose, in a few hours, its property of absorbing ammonia from the atmosphere. The addition of burned clay to soils has also a secondary influence; it renders the soil porous, and, therefore, more permeable to air and moisture.

The ammonia absorbed by the clay or ferruginous oxides is separated by every shower of rain, and conveyed in solution to the soil.

Powdered charcoal possesses a similar action, but surpasses all other substances in the power which it possesses of condensing ammonia within its pores, particularly when it has been previously heated to redness. Charcoal absorbs 90 times its volume of ammoniacal gas, which may be again separated by simply moistening it with water. (De Saussure.) Decayed wood approaches very nearly to charcoal in this power; decayed oak wood absorbs 72 times its volume, after having been completely dried under the air-pump. We have here an easy and satisfactory means of explaining still further the properties of humus, or wood in a decaying state. It is not only a slow and constant source of carbonic acid, but it is also a means by which the necessary nitrogen is conveyed to plants.

Nitrogen is found in lichens, which grow on basaltic rocks. Our fields produce more of it than we have given them as manure, and it exists in all kinds of soils and minerals which were never in contact with organic substances. The nitrogen in these cases could only have been extracted from the atmosphere.

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* The urine of the horse contains, according to Fourcroy and Vauquelin, in 1000 parts,

Urea	7 parts.
Hippurate of soda . .	24 "
Salts and water . .	979 "
	1000 parts.

† Boussingault, Ann. de Ch. et de Phys. t. lxiii. page 243.

We find this nitrogen in the atmosphere, in rain water, and in all kinds of soils, in the form of ammonia, as a product of the decay and putrefaction of preceding generations of animals and vegetables. We find likewise that the proportion of azotised matters in plants is augmented by giving them a larger supply of ammonia conveyed in the form of animal manure.

No conclusion can then have a better foundation than this, that it is the ammonia of the atmosphere which furnishes nitrogen to plants.

Carbonic acid, water and ammonia, contain the elements necessary for the support of animals and vegetables. The same substances are the ultimate products of the chemical processes of decay and putrefaction. All the innumerable products of vitality resume, after death, the original form from which they sprung. And thus death—the complete dissolution of an existing generation—becomes the source of life for a new one.

CHAPTER VI.

OF THE INORGANIC CONSTITUENTS OF PLANTS.

Carbonic acid, water and ammonia, are necessary for the existence of plants, because they contain the elements from which their organs are formed; but other substances are likewise requisite for the formation of certain organs destined for special functions peculiar to each family of plants. Plants obtain these subtances from inorganic nature. In the ashes left after the incineration of plants, the same substances are found, although in a changed condition.

Although the vital principle exercises a great power over chemical forces, yet it does so only by directing the way in which they are to act, and not by changing the laws to which they are subject. Hence when the chemical forces are employed in the processes of vegetable nutrition, they must produce the same results which are observed in ordinary chemical phenomena. The inorganic matter contained in plants must, therefore, be subordinate to the laws which regulate its combinations in common chemical processes.

The most important division of inorganic substances is that of *acids* and *alkalies*. Both of these have a tendency to unite together, and form neutral compounds, which are termed salts. According to the doctrine of equivalents, these combinations are always effected in definite proportions, that is to say, one equivalent of an acid always unites with one or two equivalents of a base, whatever that base may be. Thus 501·17 parts by weight of sulphuric acid unite with 1 eq. of potash, and form one eq. of sulphate of potash; the same quantity unites with 1 eq. of soda, and produces sulphate of soda From this fact follows the rule—that the quantity, which an acid requires of an alkali for its saturation, may be represented by a very simple number.

It is perfectly necessary to form a proper conception of what chemists denominate the "capacity for saturation of an acid," before we are able to form a correct idea of the functions performed in plants, by their inorganic constituents. The power of a base to neutralize an acid does not depend upon the quantity of radical which it contains, but altogether upon the quantity of its oxygen. Thus protoxide of iron contains 1 eq. of oxygen, and unites with 1 eq. of sulphuric acid in forming a neutral salt; but peroxide of iron contains 3 eq. of oxygen, and requires 3 eq. of the same acid for its neutralization. Hence when a given weight of an acid is neutralized by different bases, the quantity of oxygen contained in these bases must be the same as is exhibited by the following scale:—

501·17 parts of Sulphuric Acid neutralize

258·35	Magnesia	Oxygen	=100
647·29	Strontia	"	=100
1451·61	Oxide of Silver	"	=100
956·8	Barytes	"	=100

It follows from the law of equivalents, that the quantity of oxygen in a base must stand in a simple relation to the quantity of oxygen in an acid which unites with it. By this is meant, that the quantities in both cases must either be equal or multiples of each other; for the doctrine of equivalents denies the possibility of their uniting in fractional parts. This will be rendered obvious by a consideration of the two following examples:

100 parts of Cyanic Acid contain 23·26 oxygen =1.
100 parts of Cyanic Acid saturate 137·21 parts of potash, which contain 23·26 oxygen =1.
100 parts of Nitric Acid contain 73·85 oxygen =5.
100 parts of Nitric Acid saturate 214·40 parts of oxide of silver, which contain 14·77 oxygen =1.

In the first of these cases, the relation of the oxygen of the base to that of the acid is as 1:1; in the second, as 1:5. The capacity for saturation of each acid, is, therefore, the constant quantity of oxygen necessary to neutralize 190 parts of it.

Many of the inorganic constituents vary according to the soil in which the plants grow, but a certain number of them are indispensable to their developement. All substances in solution in a soil are absorbed by the roots of plants, exactly as a sponge imbibes a liquid, and all that it contains, without selection. The substances thus conveyed to plants are retained in greater or less quantity, or are entirely separated when not suited for assimilation.

Phosphate of magnesia in combination with ammonia is an invariable constituent of the seeds of all kinds of grasses. It is contained in the outer horny husk, and is introduced into bread along with the flour, and also into beer. The bran of flour contains the greatest quantity of it. It is this salt which forms large crystalline concretions, often amounting to several pounds in weight, in the *cæcum* of horses belonging to millers; and when ammonia is mixed with beer, the same salt separates as a white precipitate.

Most plants, perhaps all of them, contain organic acids of very different composition and properties, all of which are in combination with bases, such as potash, soda, lime, or magnesia. These bases evidently regulate the formation of the acids, for the diminution of the one is followed by a decrease of the other: thus in the grape, for example, the quantity of potash contained in its juice is less when it is ripe than when unripe; and the acids, under the same circumstances, are found to vary in a similar manner. Such constituents exist in small quantity in those parts of a plant in which the process of assimilation is most active, as in the mass of woody fibre; and their quantity is greater in those organs whose office it is to prepare substances conveyed to them for assimilation by other parts. The leaves contain more inorganic matters than the branches, and the branches more than the stem. The potato plant contains more potash before blossoming than after it.

The acids found in the different families of plants are of various kinds; it cannot be supposed that their presence and peculiarities are the result of accident. The fumaric and oxalic acids in the liverwort, the kinovic acid in the *China nova*, the rocellic acid in the *Rocella tinctoria*, the tartaric acid in grapes, and the numerous other organic acids, must serve some end in vegetable life. But if these acids constantly exist in vegetables, and are necessary to their life, which is incontestable, it is equally certain that some alkaline base is also indispensable, in order to enter into combination with the acids which are always found in the state of salts. All plants yield by incineration ashes containing carbonic acid; all therefore must contain salts of an organic acid.[*]

Now, as we know the capacity of saturation of organic acids to be unchanging, it follows that the quantity of the bases united with them cannot vary, and for this reason the latter substances ought to be considered with the strictest attention both by the agriculturist and physiologist.

We have no reason to believe that a plant in a condition of free and unimpeded growth produces more of its peculiar acids than it requires for its own existence; hence, a plant, on whatever soil it grows, must contain an invariable quantity of alkaline bases. Culture alone will be able to cause a deviation.

In order to understand this subject clearly, it will be necessary to bear in mind that any one of the alkaline bases may be substituted for another, the action of all being the same. Our conclusion is therefore by no means endangered by the existence of a particular alkali in one plant, which may be absent in others of the same species. If this inference be correct, the absent alkali or earth must be supplied by one similar in its mode of action, or in other words, by an equivalent of another base. The number of equivalents of these various bases which may be combined with a certain portion of acid must necessarily be the same, and therefore the amount of oxygen contained in them must remain unchanged under all circumstances and on whatever soil they grow.

Of course, this argument refers only to those alkaline bases which in the form of organic salts form constituents of the plants. Now, these salts are preserved in the ashes of plants as carbonates, the quantity of which can be easily ascertained.

It has been distinctly shown, by the analysis of De Saussure and Berthier, that the nature of a soil exercises a decided influence on the quantity of the different metallic oxides contained in the plants which grow on it; that magnesia, for example, was contained in the ashes of a pine-tree grown at Mont Breven, whilst it was absent from the ashes of a tree of the same species from Mont La Salle, and that even the proportion of lime and potash was very different.

Hence it has been concluded, (erroneously, I believe,) that the presence of bases exercises no particular influence upon the growth of plants: but even were this view correct, it must be considered as a most remarkable accident that these same analyses furnish proof for the very opposite opinion. For although the composition of the ashes of these pine-trees were so very different, they contained, according to the analyses of De Saussure, an equal number of equivalents of metallic oxides; or, what is the same thing, the quantity of oxygen contained in all the bases was in both cases the same.

100 parts of the ashes of the pine-tree from Mont Breven contained—

Carbonate of Potash .	3·60
" Lime .	46·34
" Magnesia .	6·77
Sum of the carbonates	56·71
Quantity of oxygen in the Potash	0·41
" " " Lime	7·33
" " " Magnesia	1·27
Sum of the oxygen in the bases	9·01

100 parts of the ashes of the pine from Mont La Salle contained[*]—

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[*] Salts of organic acids yield carbonates on incineration, if they contain either alkaline or earthy bases.

[*] According to the experiments of Saussure, 1000 parts of the wood of the pine from Mont Brevon gave 11·87 parts of ashes; the same quantity of wood from Mont La Salle yielded 11·28 parts. From this we might conclude that the two pines, although brought up in different soils, yet contained the same quantity of inorganic elements.

Carbonate of Potash	7·36
" Lime	51·19
" Magnesia	00·00
Sum of the carbonates	58·55
Quantity of oxygen in the Potash	0·85
" " " Lime	8·10
Sum of the oxygen in the bases	8·95

The numbers 9·01 and 8·95 resemble each other as nearly as could be expected even in analyses made for the very purpose of ascertaining the fact above demonstrated which the analyst in this case had not in view.

Let us now compare Berthier's analyses of the ashes of two fir-trees, one of which grew in Norway, the other in Allevard (département de l'Isère). One contained 50, the other 25 per cent. of soluble salts. A greater difference in the proportion of the alkaline bases could scarcely exist between two totally different plants, and yet even here the quantity of oxygen in the bases of both was the same.

100 parts of the ashes of firwood from Allevard contained, according to Berthier, (Ann. de Chim. et de Phys. t. xxxii. p. 248,)

Potash & Soda	16·8	in which	3·42	must be oxygen.
Lime	29·5	"	8.20	" "
Magnesia	3·2	"	1.20	" "
	49.5		12·82	

Only part of the potash and soda in these ashes was in combination with organic acids; the remainder was in the form of sulphates, phosphates, and chlorides. One hundred parts of the ashes contain 3·1 sulphuric acid, 4·2 phosphoric acid, and 0·3 hydrochloric acid, which together neutralize a quantity of base containing 1·20 oxygen. This number therefore must be substracted from 12·82. The remainder 11·62 indicates the quantity of oxygen in the alkaline bases, combined with organic acids in the firwood of Allevard.

The firwood of Norway contained in 100 parts,—*

Potash	14·1	of which	2·4	would be oxygen.
Soda	20·7	"	5·3	" "
Lime	12·3	"	3·45	" "
Magnesia	4·35	"	1·69	" "
	51·45		12·84	

And if the quantity of oxygen of the bases in combination with sulphuric and phosphoric acid, viz. 1·37, be again substracted from 12·84, 11·47 parts remain as the amount of oxygen contained in the bases which were in combination with organic acids.

These remarkable approximations cannot be accidental; and if further examinations confirm them in other kinds of plants, no other explanation than that already given can be adopted.

It is not known in what form silica, manganese, and oxide of iron, are contained in plants; but we are certain that potash, soda, and magnesia, can be extracted from all parts of their structure in the form of salts of organic acids. The same is the case with lime, when not present as insoluble oxalate of lime. It must here be remembered, that in plants yielding oxalic acid, the acid and potash never exist in the form of a neutral or quadruple salt, but always as a double acid salt, on whatever soil they may grow. The potash in grapes also is more frequently found as an acid salt, viz. cream of tartar, (bitartrate of potash,) than in the form of a neutral compound. As these acids and bases are never absent from plants, and as even the form in which they present themselves is not subject to change, it may be affirmed that they exercise an important influence on the developement of the fruits and seeds, and also on many other functions of the nature of which we are at present ignorant.

The quantity of alkaline bases existing in a plant also depends evidently on this circumstance of their existing only in the form of acid salts,—for the capacity of saturation of an acid is constant; and when we see oxalate of lime in the lichens occupying the place of woody fibre which is absent, we must regard it as certain that the soluble organic salts are destined to fulfil equally important though different functions, so much so that we could not conceive the complete developement of a plant without their presence, that is, without the presence of their acids, and consequently of their bases.

From these considerations we must perceive, that exact and trustworthy examinations of the ashes of plants of the same kind growing upon different soils would be of the greatest importance to vegetable physiology and would decide whether the facts above mentioned are the results of an unchanging law for each family of plants, and whether an invariable number can be found to express the quantity of oxygen which each species of plant contains in the bases united with organic acids. In all probability such inquiries will lead to most important results; for it is clear that if the production of a certain unchanging quantity of an organic acid is required by the peculiar nature of the organs of a plant, and is necessary to its existence, then potash or lime must be taken up by it in order to form salts with this acid; that if these do not exist in sufficient quantity in the soil, other bases must supply their place; and that the progress of a plant must be wholly arrested when none are present.

Seeds of the *Salsola Kali*, when sown in common garden soil, produce a plant containing both potash and soda; while the plants grown from the seeds of this contain only salts of potash, with mere traces of muriate of soda. (Cadet.)

The examples cited above, in which the quantity of oxygen contained in the bases was shown to be the same, lead us to the legitimate conclusion that the developement of certain plants is not retarded by the substitution of the bases contained in them. But it was by no means inferred that any one base could replace all the others which are found in a plant in its normal condition. On the contrary, it is known that certain bases are indispensable for the growth of a plant, and these could not be substituted without injuring its developement. Our inference has been drawn from certain plants, which can bear without injury this substitution; and it can only be extended to those plants which are in the same condition. It will be shown afterwards that corn or vines can only thrive on soils containing potash, and that this alkali is perfectly indispensable to their growth. Experiments have not been sufficiently multiplied so as to enable us to point out in what plants potash or soda may be replaced by lime or magnesia; we are only warranted in affirming that such substitutions are in many cases common. The ashes of various kinds of plants contain very different quantities of alkaline bases, such as potash, soda, lime, or magnesia. When lime exists in the ashes in large proportion, the quantity of magnesia is diminished, and in like manner according as the latter increases the lime or potash decreases. In many kinds of ashes not a trace of magnesia can be detected.

The existence of vegetable alkalies in combination with organic acids gives great weight to the opinion that alkaline bases in general are connected with the developement of plants.

If potatoes are grown where they are not supplied with earth, the magazine of inorganic bases, (in cellars, for example,) a true alkali, called Solanin, of very poisonous nature, is formed in the sprouts which extend towards the light, while not the smallest trace of such a substance can be discovered in the roots, herbs, blossoms, or fruits of potatoes grown in fields. (Otto.) In all the species of the *Cinchona*, kinic acid is found; but the quantity of quinina, cinchonina, and lime, which they contain is most variable. From the fixed bases in the products of incineration, however, we may estimate pretty accurately the quantity of the peculiar organic bases. A maximum of the first corresponds to a minimum of the latter, as must necessarily be the case if they mutually replace one another according to their equivalents. We know that different kinds of opium contain meconic acid in combination with very different quantities of narcotina, morphia, codeia, &c., the quantity of one of these alkaloids diminishing on the increase of the others. Thus the smallest quantity of morphia is accompanied by a maximum of narcotina. Not a trace of meconic acid* can be discovered in many kinds of opium, but there is not on this account an absence of acid, for the meconic is here replaced by sulphuric acid. Here, also, we have an example of what has been before stated, for in those kinds of opium where both these acids exist, they are always found to bear a certain relative proportion to one another. Attention to these facts must be very important in the selection of soils destined for the cultivation of plants which yield the vegetable alkaloids.

Now if it be found, as appears to be the case in the juice of poppies, that an organic acid may be replaced by an inorganic, without impeding the growth of a plant, we must admit the probability of this substitution taking place in a much higher degree in the case of the inorganic bases.

When roots find their more appropriate base in sufficient quantity, they will take up less of another.

These phenomena do not show themselves so frequently in cultivated plants, because they are subjected to special external conditions for the purpose of the production of particular constituents or particular organs.

When the soil, in which a white hyacinth is growing in a state of blossom, is sprinkled with the juice of the *Phytolacca decandra*, the white blossoms assume in one or two hours a red colour, which again disappears after a few days under the influence of sunshine, and they become white and colourless as before.† The juice in this case evidently enters into all parts of the plant, without being at all changed in its chemical nature, or without its presence being apparently either necessary or injurious. But this condition is not permanent, and when the blossoms have again become colourless, none of the colouring matter remains; and if it should occur that any of its elements were adapted for the purposes of nutrition of the plant, then these alone would be retained, whilst the rest would be excreted in an altered form by the roots.

Exactly the same thing must happen when we sprinkle a plant with a solution of chloride of potassium, nitre, or nitrate of strontia; they will enter into the different parts of the plant, just as the coloured juice mentioned above, and will be found in its ashes if it should be burnt at this period. Their presence is merely accidental; but no conclusion can be hence deduced against the necessity of the presence of other bases in plants. The experiments of Macaire-Princep have shown, that plants made to vegetate with their roots in a weak solution of acetate of lead, and then in rain water,

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* This calculation is exact only in the case where the quantity of ashes is equal in weight for a given quantity of wood; the difference cannot, however, be admitted to be so great as to change sensibly the above proportions. Berthier has not mentioned the proportion of ashes contained in the wood.

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* Robiquet did not obtain a trace of meconate of lime from 300 lbs. of opium, whilst in other kinds the quantity was very considerable. Ann. de Chim. liii. p. 425.

† Biot, in the Comptes rendus des Séances de l'Académie des Sciences, à Paris, 1er Sémestre, 1837, p. 12.

yield to the latter all the salt of lead which they had previously absorbed. They return, therefore, to the soil all matters which are unnecessary to their existence. Again, when a plant, freely exposed to the atmosphere, rain, and sunshine, is sprinkled with a solution of nitrate of strontia, the salt is absorbed, but it is again separated by the roots and removed farther from them by every shower of rain, which moistens the soil, so that at last not a trace of it is to be found in the plant.

Let us consider the composition of the ashes of two fir-trees as analysed by an acute and most accurate chemist. One of these grew in Norway, on a soil the constituents of which never changed, but to which soluble salts, and particularly common salt, were conveyed in great quantity by rain-water. How did it happen that its ashes contained no appreciable trace of salt, although we are certain that its roots must have absorbed it after every shower?

We can explain the absence of salt in this case by means of the direct and positive observations referred to, which have shown that plants have the power of returning to the soil all substances unnecessary to their existence; and the conclusion to which all the foregoing facts lead us, when their real value and bearing are apprehended, is that the alkaline bases existing in the ashes of plants must be necessary to their growth, since if this were not the case they would not be retained.

The perfect developement of a plant, according to this view, is dependent on the presence of alkalies or alkaline earths; for when these substances are totally wanting its growth will be arrested, and when they are only deficient it must be impeded.

In order to apply these remarks, let us compare two kinds of trees, the wood of which contains unequal quantities of alkaline bases, and we shall find that one of these grows luxuriantly in several soils upon which the others are scarcely able to vegetate. For example, 10,000 parts of oak wood yield 250 parts of ashes, the same quantity of fir wood only 83, of linden wood 500, of rye 440, and of the herb of the potato plant 1500 parts.[*]

Firs and pines find a sufficient quantity of alkalies in granitic and barren sandy soils in which oaks will not grow; and wheat thrives in soils favourable for the linden tree, because the bases which are necessary to bring it to complete maturity, exist there in sufficient quantity. The accuracy of these conclusions, so highly important to agriculture and to the cultivation of forests, can be proved by the most evident facts.

All kinds of grasses, the *Equisetaceæ*, for example, contain in the outer parts of their leaves and stalk a large quantity of silicic acid and potash in the form of acid silicate of potash. The proportion of this salt does not vary perceptibly in the soil of corn-fields, because it is again conveyed to them as manure in the form of putrefying straw. But this is not the case in a meadow, and hence we never find a luxuriant crop of grass[*] on sandy and calcareous soils, which contain little potash, evidently because one of the constituents indispensable to the growth of the plants is wanting. Soils formed from basalt, grauwacke, and porphyry are, ***cæteris paribus***, the best for meadow land, on account of the quantity of potash which enters into their composition. The potash abstracted by the plants is restored during the annual irrigation. The potash contained in the soil itself is inexhaustible in comparison with the quantity removed by plants. But when we increase the crop of grass in a meadow by means of gypsum, we remove a greater quantity of potash with the hay than can under the same circumstances be restored. Hence it happens that, after the lapse of several years, the crops of grass on the meadows manured with gypsum diminish, owing to the deficiency of potash. But if the meadow be strewed from time to time with wood-ashes, even with the lixiviated ashes which have been used by soap-boilers, (in Germany much soap is made from the ashes of wood,) then the grass thrives as luxuriantly as before. The ashes are only a means of restoring the potash.

A harvest of grain is obtained every thirty or forty years from the soil of the Luneburg heath, by strewing it with the ashes of the heath plants (*Erica vulgaris*) which grow on it. These plants during the long period just mentioned collect the potash and soda, which are conveyed to them by rain-water; and it is by means of these alkalies that oats, barley, and rye, to which they are indispensable, are enabled to grow on this sandy heath.

The woodcutters in the vicinity of Heidelberg have the privilege of cultivating the soil for their own use, after felling the trees used for making tan. Before sowing the land thus obtained, the branches, roots, and leaves, are in every case burned, and the ashes used as a manure, which is found to be quite indispensable for the growth of the grain. The soil itself upon which the oats grow in this district consists of sandstone; and although the trees find in it a quantity of alkaline earths sufficient for their own sustenance, yet in its ordinary condition it is incapable of producing grain.

The most decisive proof of the use of strong manure was obtained at Bingen (a town on the Rhine,) where the produce and developement of vines were highly increased by manuring them with such substances as shavings of horn, &c.; but after some years the formation of the wood and leaves decreased to the great loss of the possessor, to such a degree that he has long had cause to regret his departure from the usual methods. By the manure employed by him, the vines had been too much hastened in their growth; in two or three years they had exhausted the potash in the formation of their fruit, leaves, and wood, so that none remained for the future crops, his manure not having contained any potash.

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[*] Berthier, Annalos de Chimie et de Physique, t. xxx. p. 248.

[*] It would be of importance to examine what alkalies are contained in the ashes of the sea-shore plants which grow in the humid hollows of downs, and especially in those of the millet-grass. If potash is not found in them, it must certainly be replaced by soda as in the *Salsola*, or by lime as in the *Plumbagineæ*.

There are vineyards on the Rhine the plants of which are a hundred years old, and all of these have been cultivated by manuring them with a cow-dung, a manure containing a large proportion of potash, although very little nitrogen. All the potash, in fact, which is contained in the food consumed by a cow is again immediately discharged in its excrements.

The experience of a proprietor of land in the vicinity of Göttingen offers a most remarkable example of the incapability of a soil to produce wheat or grasses in general, when it fails in any one of the materials necessary to their growth. In order to obtain potash, he planted his whole land with wormwood, the ashes of which are well known to contain a large proportion of the carbonate of that alkali. The consequence was, that he rendered his land quite incapable of bearing grain for many years, in consequence of having entirely deprived the soil of its potash.

The leaves and small branches of trees contain the most potash; and the quantity of them which is annually taken from a wood for the purpose of being employed as litter,[*] contain more of that alkali than all the old wood which is cut down. The bark and foliage of oaks, for example, contain from 6 to 9 per cent. of this alkali; the needles of firs and pines, 8 per cent.

With every 2650 lbs. of firwood which are yearly removed from an acre of forest, only from 0·114 to 0·53 lbs. of alkalies are abstracted from the soil, calculating the ashes at 0·83 per cent. The moss, however, which covers the ground, and of which the ashes are known to contain so much alkali, continues uninterrupted in its growth, and retains that potash on the surface, which would otherwise so easily penetrate with the rain through the sandy soil. By its decay, an abundant provision of alkalies is supplied to the roots of the trees, and a fresh supply is rendered unnecessary.

The supposition of alkalies, metallic oxides, or inorganic matter in general, being produced by plants, is entirely refuted by these well-authenticated facts.

It is thought very remarkable, that those plants of the grass tribe, the seeds of which furnish food for man, follow him like the domestic animals. But saline plants seek the sea-shore or saline springs, and the Chenopodium the dunghill from similar causes. Saline plants require common salt, and the plants which grow only on dunghills need ammonia and nitrates, and they are attracted whither these can be found, just as the dung-fly is to animal excrements. So likewise none of our corn-plants can bear perfect seeds, that is, seeds yielding flour, without a large supply of phosphate of magnesia and ammonia, substances which they require for their maturity. And hence, these plants grow only in a soil where these three constituents are found combined, and no soil is richer in them than those where men and animals dwell together; where the urine and excrements of these are found corn-plants appear, because their seeds cannot attain maturity unless supplied with the constituents of those matters.

When we find sea-plants near our salt-works, several hundred miles distant from the sea, we know that their seeds have been carried there in a very natural manner, namely, by wind or birds, which have spread them over the whole surface of the earth, although they grow only in those places in which they find the conditions essential to their life.

Numerous small fish, of not more than two inches in length (*Gasterosteus aculeatus*,) are found in the salt-pans of the graduating house at Nidda (a village in Hesse Darmstadt.) No living animal is found in the salt-pans of Neuheim, situated about 18 miles from Nidda; but the water there contains so much carbonic acid and lime, that the walls of the graduating house are covered with stalactites. Hence the eggs conveyed to this place by birds do not find the conditions necessary for their developement, which they found in the former place.[*]

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[*] [This refers to a custom some time since very prevalent in Germany although now discontinued. The leaves and small twigs of trees were gleaned from the forests by poor people, for the purpose of being used as litter for their cattle. The trees, however, were found to suffer so much in consequence, that their removal is strictly prohibited. The cause of the injury was that stated in the text.—Ed.]

[*] The itch-insect (*Acarus Scabiei*) is considered by Burdach as the production of a morbid condition, so likewise lice in children; the original generation of the fresh-water muscle (*mytilus*) in fish-ponds, of sea-plants in the vicinity of salt-works, of nettles and grasses, of fish in pools of rain, of trout in mountain streams, &c., is according to the same natural philosopher not impossible. A soil consisting of crumbled rocks, decayed vegetables, rain and salt water, &c., is here supposed to possess the power of generating shell-fish, trout, and saltwort (*salicornia.*) All inquiry is arrested by such opinions, when propagated by a teacher who enjoys a merited reputation, obtained by knowledge and hard labour. These subjects, however, have hitherto met with the most superficial observation, although they well merit strict investigation. The dark, the secret, the mysterious, the enigmatic, is, in fact, too seducing for the youthful and philosophic

How much more wonderful and inexplicable does it appear, that bodies which remained fixed in the strong heat of a fire, have under certain conditions the property of volatilizing and, at ordinary temperatures, of passing into a state, of which we cannot say whether they have really assumed the form of a gas or are dissolved in one! Steam or vapours in general have a very singular influence in causing the volatilization of such bodies, that is, of causing them to assume the gaseous form. A liquid during evaporation communicates the power of assuming the same state in a greater or less degree to all substances dissolved in it, although they do not of themselves possess that property.

Boracic acid is a substance which is completely fixed in the fire; it suffers no change of weight appreciable by the most delicate balance, when exposed to a white heat, and, therefore, it is not volatile. Yet its solution in water cannot be evaporated by the gentlest heat, without the escape of a sensible quantity of the acid with the steam. Hence it is that a loss is always experienced in the analysis of minerals containing this acid, when liquids in which it is dissolved are evaporated. The quantity of boracic acid which escapes with a cubic foot of steam, at the temperature of boiling water, cannot be detected by our most sensible re-agents; and nevertheless the many hundred tons annually brought from Italy as an article of commerce, are procured by the uninterrupted accumulation of this apparently inappreciable quantity. The hot steam which issues from the interior of the earth is allowed to pass through cold water in the lagoons of Castel Nuova and Cherchiago; in this way the boracic acid is gradually accumulated, till at last it may be obtained in crystals by the evaporation of the water. It is evident, from the temperature of the steam, that it must have come out of depths in which human beings and animals never could have lived, and yet it is very remarkable and highly important that ammonia is never absent from it. In the large works in Liverpool, where natural boracic acid is converted into borax, many hundred pounds of sulphate of ammonia are obtained at the same time.

This ammonia has not been produced by the animal organism, it existed before the creation of human beings; it is a part, a primary constituent, of the globe itself.

The experiments instituted under Lavoisier's guidance by the *Direction des Poudres et Salpêtres*, have proved that during the evaporation of the saltpetre ley, the salt volatilizes with the water, and causes a loss which could not before be explained. It is known also, that in sea storms, leaves of plants in the direction of the wind are covered with crystals of salt, even at the distance of from 20 to 30 miles from the sea. But it does not require a storm to cause the volatilization of the salt, for the air hanging over the sea always contains enough of this substance to make a solution of nitrate of silver turbid, and every breeze must carry this away. Now, as thousands of tons of sea water annually evaporate into the atmosphere, a corresponding quantity of the salts dissolved in it, viz. of common salt, chloride of potassium, magnesia, and the remaining constituents of the sea water, will be conveyed by wind to the land.

This volatilization is a source of considerable loss in salt works, especially where the proportion of salt in the water is not large. This has been completely proved at the salt works of Nauheim, by the very intelligent director of that establishment, M. Wilhelmi. He hung a plate of glass between two evaporating houses, which were about 1200 paces distant from each other, and found in the morning, after the drying of the dew, that the glass was covered with crystals of salt on one or the other side, according to the direction of the wind.

By the continual evaporation of the sea, its salts* are spread over the whole surface of the earth; and being subsequently carried down by the rain, furnish to the vegetation those salts necessary to its existence. This is the origin of the salts found in the ashes of plants, in those cases where the soil could not have yielded them.

In a comprehensive view of the phenomena of nature, we have no scale for that which we are accustomed to name, small or great; all our ideas are proportioned to what we see around us, but how insignificant are they in comparison with the whole mass of the globe! that which is scarcely observable in a confined district appears inconceivably large when regarded in its extension through unlimited space The atmosphere contains only a thousandth part of its weight of carbonic acid; and yet small as this proportion appears, it is quite sufficient to supply the whole of the present generation of living beings with carbon for a thousand years, even if it were not renewed. Sea-water contains $\frac{1}{12400}$ of its weight of carbonate of lime; and this quantity, although scarcely appreciable in a pound, is the source from which myriads of marine mollusca and corals are supplied with materials for their habitations.

Whilst the air contains only from 4 to 6 ten-thousandth parts of its volume of carbonic acid, sea-water contains 100 times more, (10,000 volumes of sea-water contain 620 volumes of carbonic acid—Laurent, Bouillon, Lagrange.) Ammonia* is also found in this water, so that the same conditions which sustain living beings on the land are combined in this medium, in which a whole world of other plants and animals exist.

The roots of plants are constantly engaged in collecting from the rain those alkalies which formed part of the sea-water, and also those of the water of springs, which penetrates the soil. Without alkalies and alkaline bases most plants could not exist, and without plants the alkalies would disappear gradually from the surface of the earth.

When it is considered, that sea-water contains less than one-millionth of its own weight of iodine, and that all combinations of iodine with the metallic bases of alkalies are highly soluble in water, some provision must necessarily be supposed to exist in the organization of sea-weed and the different kinds of Fuci, by which they are enabled during their life to extract iodine in the form of a soluble salt from sea-water, and to assimilate it in such a manner, that it is not again restored to the surrounding medium. These plants are collectors of iodine, just as land plants are of alkalies; and they yield us this element, in quantities such as we could not otherwise obtain from the water without the evaporation of whole seas.

We take it for granted that the sea-plants require metallic iodides for their growth, and that their existence is dependent on the presence of those substances. With equal justice, then, we conclude, that the alkalies and alkaline earths, always found in the ashes of land-plants, are likewise necessary for their developement.

CHAPTER VII.

THE ART OF CULTURE.

The conditions necessary for the life of all vegetables have been considered in the preceding part of the work. Carbonic acid, ammonia, and water yield elements for all the organs of plants. Certain inorganic substances—salts and metallic oxides—serve peculiar functions in their organism, and many of them must be viewed as essential constituents of particular parts.

The atmosphere and the soil offer the same kind of nourishment to the leaves and roots. The former contains a comparatively inexhaustible supply of carbonic acid and ammonia; the latter, by means of its humus, generates constantly fresh carbonic acid, whilst, during the winter, rain and snow introduce into the soil a quantity of ammonia, sufficient for the developement of the leaves and blossoms.

The complete, or it may be said, the absolute insolubility in cold water of vegetable matter in progress of decay, (humus,) appears on closer consideration to be a most wise arrangement of nature. For if humus possessed even a smaller degree of solubility than that ascribed to the substance called humic acid, it must be dissolved by rain-water. Thus, the yearly irrigation of meadows, which last for several weeks, would remove a great part of it from the ground, and a heavy and continued rain would impoverish the soil. But it is soluble only when combined with oxygen; it can be taken up by water, therefore, only as carbonic acid.

When kept in a dry place, humus may be preserved for centuries; but when moistened with water, it converts the surrounding oxygen into carbonic acid. As soon as the action of the air ceases, that is, as soon as it is deprived of oxygen, the humus suffers no farther change. Its decay proceeds only when plants grow in the soil containing it; for they absorb by their roots the carbonic acid as it is formed. The soil receives again from living plants the carbonaceous matter it thus loses, so that the proportion of humus in it does not decrease.

The stalactitic caverns in Franconia, and those in the vicinity of Baireuth, and Streitberg, lie beneath a fertile arable soil; the abundant decaying vegetables or humus in this soil, being acted on by moisture and air, constantly evolve carbonic acid, which is dissolved by the rain. The rain-water thus impregnated permeates the porous limestone, which forms the walls and roofs of the caverns, and dissolves in its passage as much carbonate of lime as corresponds to the quantity of carbonic acid contained in it. Water and the excess of carbonic acid evaporate from this solution when it has reached the interior of the caverns, and the limestone is deposited on the walls and roofs in crystalline crusts of various forms. There are few spots on the earth where so many circumstances favourable to the production of humate of lime are combined, if the humus actually existed in the soil in the form of humic acid. Decaying vegetable matter, water, and lime in solution, are brought together, but the stalactites formed contain no

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mind, which would penetrate the deepest depths of nature, without the assistance of the shaft or ladder of the miner. This is poetry, but not sober philosophical inquiry.

* According to Marcet, sea-water contains in 1000 parts,

26·660	Chloride of Sodium.
4·660	Sulphate of Soda.
1·232	Chloride of Potassium.
5·152	Chloride of Magnesium.
0·153	Sulphate of Lime.

According to M'Clemm, the water of the North Sea contains in 1000 parts,

24·84	Chloride of Sodium.
2·42	Chloride of Magnesium.
2·06	Sulphate of Magnesia.
1·25	Chloride of Potassium.
1·20	Sulphate of Lime.

In addition to these constituents, it also contains inappreciable quantities of carbonate of lime, magnesia, iron, manganese, phosphate of lime, iodides and bromides, silica, sulphuretted hydrogen, and organic matter, together with ammonia and carbonic acid. (Liebig's *Annalen der Chemie*, Bd. xxxvii. s. 3.)

* When the solid saline residue obtained by the evaporation of sea-water is heated in a retort to redness, a sublimate of sal-ammoniac is obtained. —MARCET.

trace of vegetable matter, and no humic acid; they are of a glistening white or yellowish colour, and in part transparent, like calcareous spar, and may be heated to redness without becoming black.

The subterranean vaults in the old castles near the Rhine, the "Bergstrass," and Wetherau, are constructed of sandstone, granite, or basalt, and present appearances similar to the limestone caverns. The roofs of these vaults or cellars are covered externally to the thickness of several feet with vegetable mould, which has been formed by the decay of plants. The rain falling upon them sinks through the earth, and dissolves the mortar by means of the carbonic acid derived from the mould; and this solution evaporating in the interior of the vaults, covers them with small thin stalactites, which are quite free from humic acid.

In such a filtering apparatus, built by the hand of nature, we have placed before us experiments which have been continued for a hundred or thousand years. Now, if water possessed the power of dissolving a hundredth thousandth part of its own weight of humic acid or humate of lime, and humic acid were present, we should find the inner surface of the roofs of these vaults and caverns covered with these substances; but we cannot detect the smallest trace of them. There could scarcely be found a more clear and convincing proof of the absence of the humic acid of chemists in common vegetable mould.

The common view, which has been adopted respecting the *modus operandi* of humic acid, does not afford any explanation of the following phenomenon:—A very small quantity of humic acid dissolved in water gives it a yellow or brown colour. Hence it would be supposed that a soil would be more fruitful in proportion as it was capable of giving this colour to water, that is, of yielding it humic acid. But it is very remarkable that plants do not thrive in such a soil, and that all manure must have lost this property before it can exercise a favourable influence upon their vegetation. Water from barren peat soils and marshy meadows, upon which few plants flourish, contains much of this humic acid; but all agriculturists and gardeners agree that the most suitable and best manure for plants is that which has completely lost the property of giving a colour to water.

The soluble substance, which gives to water a brown colour, is the product of the putrefaction of all animal and vegetable matter; its formation is an evidence that there is not oxygen sufficient to begin, or at least to complete the decay. The brown solutions containing this substance are decolourised in the air by absorbing oxygen, and a black coaly matter precipitates—the substance named "coal of humus." Now if a soil were impregnated with this matter, the effect on the roots of plants would be the same as that of entirely depriving the soil of oxygen; plants would be as little able to grow in such ground as they would if hydrated protoxide of iron were mixed with the soil. Indeed some barren soils have been found to owe their fertility to this very cause The sulphate of protoxide of iron (copperas,) which forms a constituent of these soils, possesses a powerful affinity for oxygen, and consequently prevents the absorption of that gas by the roots of plants in its vicinity.[*] All plants die in soils and water which contain no oxygen; absence of air acts exactly in the same manner as an excess of carbonic acid. Stagnant water on a marshy soil excludes air, but a renewal of water has the same effect as a renewal of air, because water contains it in solution. If the water is withdrawn from a marsh, free access s given to the air, and the marsh is changed into a fruitful meadow.

In a soil to which the air has no access, or at most but very little, the remains of animals and vegetables do not decay, for they can only do so when freely supplied with oxygen; but they undergo putrefaction, for which air is present in sufficient quantity. Putrefaction is known to be a most powerful deoxidising process, the influence of which extends to all surrounding bodies, even to the roots and the plants themselves. All substances from which oxygen can be extracted yield it to putrefying bodies; yellow oxide of iron passes into the state of black oxide, sulphate of iron into sulphuret of iron, &c.

The frequent renewal of air by ploughing and the preparation of the soil, especially its contact with alkaline metallic oxides, the ashes of brown coal, burnt lime or limestone, change the putrefaction of its organic constituents into a pure process of oxidation; and from the moment at which all the organic matter existing in a soil enters into a state of oxidation or decay, its fertility is increased. The oxygen is no longer employed for the conversion of the brown soluble matter into the insoluble coal of humus, but serves for the formation of carbonic acid. This change takes place very slowly, and in some instances the oxygen is completely excluded by it; and whenever this happens, the soil loses its fertility. Thus, in the vicinity of Salzhausen (a village in Hesse Darmstadt, famed for its mineral springs, upon a meadow called Grünschwalheimer, unfruitful spots are seen here and there covered with a yellow grass. If a hole be bored from twenty to twenty-five feet deep in one of these spots, carbonic acid is emitted from it with such violence that the noise made by the escape of the gas may be distinctly heard at the distance of several feet. Here the carbonic acid rising to the surface displaces completely all the air, and consequently all the oxygen, from the soil; and and without oxygen neither seeds nor roots can be developed; a plant will not vegetate in pure nitrogen or carbonic acid gas.

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[*] The most obvious method of removing this salt from soils in which it may be contained is to manure the land with lime. The lime unites with the sulphuric acid and liberates the protoxide of iron, which absorbs oxygen with much rapidity, and is converted into the peroxide of iron. This conversion is accelerated by giving free access to the air. that is, by loosening the soil.

Humus supplies young plants with nourishment by the roots, until their leaves are matured sufficiently to act as exterior organs of nutrition; its quantity heightens the fertility of a soil by yielding more nourishment in this first period of growth, and consequently by increasing the number of organs of atmospheric nutrition. Those plants which receive their first food from the substance of their seeds, such as bulbous plants, could completely dispense with humus; its presence is useful only in so far as it increases and accelerates their developement, but it is not necessary—indeed, an excess of it at the commencement of their growth is in a certain measure injurious.

The amount of food which young plants can take from the atmosphere in the form of carbonic acid and ammonia is limited; they cannot assimilate more than the air contains. Now, if the quantity of their stems, leaves, and branches has been increased by the excess of food yielded by the soil at the commencement of their developement, they will require for the completion of their growth, and for the formation of their blossoms and fruits, more nourishment from the air than it can afford, and consequently they will not reach maturity. In many cases the nourishment afforded by the air under these circumstances suffices only to complete the formation of the leaves, stems, and branches. The same result then ensues as when ornamental plants are transplanted from the pots in which they have grown to larger ones, in which their roots are permitted to increase and multiply. All their nourishment is employed for the increase of their roots and leaves; they spring, as it is said, into an herb or weed, but do not blossom. When, on the contrary, we take away part of the branches, and of course their leaves with them, from dwarf trees, since we thus prevent the developement of new branches, an excess of nutriment is artificially procured for the trees, and is employed by them in the increase of the blossoms and enlargement of the fruit. It is to effect this purpose that vines are pruned.

A new and peculiar process of vegetation ensues in all perennial plants, such as shrubs, fruit and forest trees, after the complete maturity of their fruit. The stem of annual plants at this period of their growth becomes woody, and their leaves change in colour. The leaves of trees and shrubs, on the contrary, remain in activity until the commencement of the winter. The formation of the layers of wood progresses, the wood becomes harder and more solid, but after August the leaves form no more wood; all the carbonic acid which the plants now absorb is employed for the production of nutritive matter for the following year: instead of woody fibre, starch is formed, and is diffused through every part of the plant by the autumnal sap (sève d'Août.)[*] According to the observations of M. Heyer, the starch thus deposited in the body of the tree can be recognised in its known form by the aid of a good microscope. The barks of several aspens and pine-trees[†] contain so much of this substance, that it can be extracted from them as from potatoes by trituration with water. It exists also in the roots and other parts of perennial plants. A very early winter, or sudden change of temperature, prevents the formation of this provision for the following year; the wood, as in the case of the vine-stock, does not ripen, and its growth is in the next year very limited.

From the starch thus accumulated, sugar and gum are produced in the succeeding spring, while from the gum those constituents of the leaves and young sprouts which contain no nitrogen are in their turn formed. After potatoes have germinated, the quantity of starch in them is found diminished. The juice of the maple-tree ceases to be sweet from the loss of its sugar when its buds, blossoms, and leaves attain their maturity.

The branch of a willow, which contains a large quantity of granules of starch in every part of its woody substance, puts forth both roots and leaves in pure distilled rain-water; but in proportion as it grows, the starch disappears, it being evidently exhausted for the formation of the roots and leaves. In the course of these experiments, M. Heyer made the interesting observation, that such branches when placed in snow water (which contains ammonia) produced roots three or four times longer than those which they formed in pure distilled water, and that this pure water remained clear, while the rain-water gradually acquired a yellow colour.

Upon the blossoming of the sugar-cane, likewise, part of the sugar disappears; and it has been ascertained, that the sugar does not accumulate in the beet-root until after the leaves are completely formed.

Much attention has recently been drawn to the fact that the produce of potatoes may be much increased by plucking off the blossoms from the plants producing them, a result quite consistent with theory This important observation has been completely confirmed by M. Zeller, the director of the Agricultural Society at Darmstadt. In the year 1839, two fields of the same size, lying side by side and manured in the same manner, were planted with potatoes. When the plants had flowered, the blossoms were removed from those in one field, while those in the other field were left untouched. The former produced 47 bolls, the latter only 37 bolls.

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[*] Hartig, in Erdmann und Schweigger-Seidels Journal, V. 217. 1835.

[†] It is well known that bread is made from the bark of pines in Sweden during famines.

These well-authenticated observations remove every doubt as to the part which sugar, starch, and gum play in the developement of plants; and it ceases to be enigmatical, why these three substances exercise no influence on the growth or process of nutrition of a matured plant, when supplied to them as food.

The accumulation of starch in plants during the autumn has been compared, although certainly erroneously, to the fattening of hibernating animals before their winter sleep; but in these animals every vital function, except the process of respiration, is suspended, and they only require, like a lamp slowly burning, a substance rich in carbon and hydrogen to support the process of combustion in the lungs. On their awaking from their torpor in the spring, the fat has disappeared, but has not served as nourishment. It has not caused the least increase in any part of their body, neither has it changed the quality of any of their organs. With nutrition, properly so called, the fat in these animals has not the least connexion.

The annual plants form and collect their future nourishment in the same way as the perennial; they store it in their seeds in the form of vegetable albumen, starch and gum, which are used by the germs for the formation of their leaves and first radicle fibres. The proper nutrition of the plants, their increase in size, begins after these organs are formed.

Every germ and every bud of a perennial plant is the engrafted embryo of a new individual, while the nutriment accumulated in the stem and roots, corresponds to the albumen of the seeds.

Nutritive matters are, correctly speaking, those substances which, when presented from without, are capable of sustaining the life and all the functions of an organism, by furnishing to the different parts of plants the materials for the production of their peculiar constituents.

In animals, the blood is the source of the material of the muscles and nerves; by one of its component parts, the blood supports the process of respiration, by others, the peculiar vital functions; every part of the body is supplied with nourishment by it, but its own production is a special function, without which we could not conceive life to continue. If we destroy the activity of the organs which produce it, or if we inject the blood of one animal into the veins of another, at all events, if we carry this beyond certain limits, death is the consequence.

If we could introduce into a tree woody fibre in a state of solution, it would be the same thing as placing a potato plant to vegetate in a paste of starch. The office of the leaves is to form starch, woody fibre, and sugar; consequently, if we convey these substances through the roots, the vital functions of the leaves must cease, and if the process of assimilation cannot take another form, the plant must die.

Other substances must be present in a plant, besides the starch, sugar and gum, if these are to take part in the developement of the germ, leaves, and first radicle fibres. There is no doubt that a grain of wheat contains within itself the component parts of the germ and of the radicle fibres, and, we must suppose, exactly in the proportion necessary for their formation. These component parts are starch and gluten; and it is evident that neither of them alone, but that both simultaneously assist in the formation of the root, for they both suffer changes under the action of air, moisture, and a suitable temperature. The starch is converted into sugar, and the gluten also assumes a new form, and both acquire the capability of being dissolved in water, and of thus being conveyed to every part of the plant. Both the starch and the gum are completely consumed in the formation of the first part of the roots and leaves; and excess of either could not be used in the formation of leaves, or in any other way.

The conversion of starch into sugar during the germination of grain is ascribed to a vegetable principle called *diastase*, which is generated during the act of commencing germination. But this mode of transformation can also be effected by gluten, although it requires a longer time. Seeds, which have germinated, always contain much more diastase than is necessary for the conversion of their starch into sugar, for five parts by weight of starch can be converted into sugar by one part of malted barley. This excess of diastase can by no means be regarded as accidental, for, like the starch, it aids in the formation of the first organs of the young plant, and disappears with the sugar; diastase contains nitrogen and furnishes the elements of vegetable albumen.

Carbonic acid, water, and ammonia, are the food of fully-developed plants; starch, sugar, and gum, serve, when accompanied by an azotised substance, to sustain the embryo, until its first organs of nutrition are unfolded. The nutrition of a fœtus and developement of an egg proceed in a totally different manner from that of an animal which is separated from its parent; the exclusion of air does not endanger the life of the fœtus, but would certainly cause the death of the independent animal. In the same manner, pure water is more advantageous to the growth of a young plant, than that containing carbonic acid, but after a month the reverse is the case.

The formation of sugar in maple-trees does not take place in the roots, but in the woody substance of the stem. The quantity of sugar in the sap augments until it reaches a certain height in the stem of the plant, above which point it remains stationary.

Just as germinating barley produces a substance which, in contact with starch, causes it to lose its insolubility and to become sugar, so in the roots of the maple, at the commencement of vegetation, a substance must be formed, which, being dissolved in water, permeates the wood of the trunk, and converts into sugar the starch, or whatever it may be, which it finds deposited there. It is certain, that when a hole is bored into the trunk of a maple-tree just above its roots, filled with sugar, and then closed again, the sugar is dissolved by the ascending sap. It is further possible that this sugar may be disposed of in the same manner as that formed in the trunks; at all events it is certain, that the introduction of it does not prevent the action of the juice upon the starch, and since the quantity of the sugar present is now greater than can be exhausted by the leaves and buds, it is excreted from the surface of the leaves or bark. Certain diseases of trees, for example that called honey-dew, evidently depend on the want of the due proportion between the quantity of the azotised and that of the unazotised substances which are applied to them as nutriment.

In whatever form, therefore, we supply plants with those substances which are the products of their own action, in no instance do they appear to have any effect upon their growth, or to replace what they have lost. Sugar, gum, and starch, are not food for plants, and the same must be said of humic acid, which is so closely allied to them in composition.

If now we direct our attention to the particular organs of a plant, we find every fibre and every particle of wood surrounded by a juice containing an azotised matter; while the starch, granules, and sugar are enclosed in cells formed of a substance containing nitrogen. Indeed every where, in all the juices of the fruits and blossoms, we find a substance destitute of nitrogen, accompanied by one which contains that element.

The wood of the stem cannot be formed, *quasi* wood, in the leaves, but another substance must be produced which is capable of being transformed into wood. This substance must be in a state of solution, and accompanied by a compound containing nitrogen; it is very probable that the wood and the vegetable gluten, the starch granules and the cells containing them, are formed simultaneously, and in this case a certain fixed proportion between them would be a condition necessary for their production.

According to this view, the assimilation of the substances generated in the leaves will (*cæteris paribus*) depend on the quantity of nitrogen contained in the food. When a sufficient quantity of nitrogen is not present to aid in the assimilation of the substances which do not contain it, these substances will be separated as excrements from the bark, roots, leaves, and branches. The exudations of mannite, gum, and sugar, in strong and healthy plants cannot be ascribed to any other cause.*

Analogous phenomena are presented by the process of digestion in the human organism. In order that the loss which every part of the body sustains by the processes of respiration and perspiration may be restored to it, the organs of digestion require to be supplied with food, consisting of substances containing nitrogen, and of others destitute of it, in definite proportions. If the substances which do not contain nitrogen preponderate, either they will be expended in the formation of fat, or they will pass unchanged through the organism. This is particularly observed in those people who live almost exclusively upon potatoes; their excrements contain a large quantity of unchanged granules of starch, of which no trace can be detected when gluten or flesh is taken in proper proportions, because in this case the starch has been rendered capable of assimilation. Potatoes, which when mixed with hay alone are scarcely capable of supporting the strength of a horse, form with bread and oats a strong and wholesome fodder.

It will be evident from the preceding considerations, that the products generated by a plant may vary exceedingly, according to the substances given it as food. A superabundance of carbon in the state of carbonic acid conveyed through the roots of plants, without being accompanied by nitrogen, cannot be converted either into gluten, albumen, wood, or any other component part of an organ; but either it will be separated in the form of excrements, such as sugar, starch, oil, wax, resin, mannite, or gum, or these substances will be deposited in greater or less quantity in the wide cells and vessels.

The quantity of gluten, vegetable albumen, and mucilage, will augment when plants are supplied with an excess of food containing nitrogen; and ammoniacal salts will remain in the sap, when, for example, in the culture of the beet, we manure the soil with a highly nitrogenous substance, or when we suppress the functions of the leaves by removing them from the plant.

We know that the ananas is scarcely eatable in its wild state, and that it shoots forth a great quantity of leaves when treated with rich animal manure, without the fruit on that account acquiring a large amount of sugar; that the quantity of starch in potatoes increases when the soil contains much humus, but decreases when the soil is manured with strong animal manure, although then the number of cells increases, the potatoes acquiring in the first case a mealy, in the second a soapy, consistence. Beet-roots, taken from a barren, sandy soil, contain a maximum of sugar, and no ammoniacal salts; and the Teltowa parsnep loses its mealy state in a manured land, because there all the circumstances necessary for the formation of cells are united.*

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* M. Trapp, in Giessen, possesses a *Clerodendron fragrans*, which grows in the house, and exudes on the surface of its leaves in September large colourless drops of sugar-candy, which form regular crystals upon drying;—I am not aware whether the juice of this plant contains sugar. Professor Redtenbacher, of Prague, informs me that he has analysed the crystals, and found them to be perfectly pure sugar.—Ed.

An abnormal production of certain component parts of plants presupposes a power and capability of assimilation to which the most powerful chemical action cannot be compared. The best idea of it may be formed by considering that it surpasses in power the strongest galvanic battery, with which we are not able to separate the oxygen from carbonic acid. The affinity of chlorine for hydrogen, and its power to decompose water under the influence of light and set at liberty its oxygen, cannot be considered as at all equalling the power and energy with which a leaf separated from a plant decomposes the carbonic acid which it absorbs.

The common opinion, that only the direct solar rays can effect the decomposition of carbonic acid in the leaves of plants, and that reflected or diffused light does not possess this property, is wholly an error, for exactly the same constituents are generated in a number of plants, whether the direct rays of the sun fall upon them, or whether they grow in the shade. They require light, and indeed sun-light, but it is not necessary that the direct rays of the sun reach them. Their functions certainly proceed with greater intensity and rapidity in sunshine than in the diffused light of day; but there is nothing more in this than the similar action which light exercises on ordinary chemical combinations; it merely accelerates in a greater or less degree the action already subsisting.

Thus chlorine and hydrogen combining form muriatic acid. This combination is effected in a few hours in common daylight, but it ensues instantly, with a violent explosion, under exposure to the direct solar rays, whilst not the slightest change in the two gases takes place in perfect darkness. When the liquid hydrocarburet of chlorine, resulting from the union of the olefiant gas of the associated Dutch chemists with chlorine, is exposed in a vessel with chlorine gas to the direct solar rays, chloride of carbon is immediately produced; but the same compound can be obtained with equal facility in the diffused light of day, a longer time only being required. When this experiment is performed in the way first mentioned, two products only are observed (muriatic acid and perchloride of carbon); whilst by the latter method a class of intermediate bodies are produced, in which the quantity of chlorine constantly augments, until at last the whole liquid hydrocarburet of chlorine is converted into the same two products as in the first case. Here, also, not the slightest trace of decomposition takes place in the dark. Nitric acid is decomposed in common daylight into oxygen, and peroxide of nitrogen; and chloride of silver becomes black in the diffused light of day, as well as in the direct solar rays;—in short, all actions of a similar kind proceed in the same way in diffused light as well as in the solar light, the only difference consisting in the time in which they are effected. It cannot be otherwise in plants, for the mode of their nutriment is the same in all, and their component substances afford proof that their food has suffered absolutely the same change, whether they grow in the sunshine or in the shade.

All the carbonic acid, therefore, which we supply to a plant will undergo a transformation, provided its quantity be not greater than can be decomposed by the leaves. We know that an excess of carbonic acid kills plants, but we know also that nitrogen to a certain degree is not essential for the decomposition of carbonic acid. All the experiments hitherto instituted prove, that fresh leaves placed in water impregnated with carbonic acid, and exposed to the influence of solar light, emit oxygen gas, whilst the carbonic acid disappears. Now in these experiments no nitrogen is supplied at the same time with the carbonic acid; hence no other conclusion can be drawn from them than that nitrogen is not necessary for the decomposition of carbonic acid, —for the exercise, therefore, of one of the functions of plants. And yet the presence of a substance containing this element appears to be indispensable for the assimilation of the products newly formed by the decomposition of the carbonic acid, and their consequent adaptation for entering into the composition of the different organs.

The carbon abstracted from the carbonic acid acquires in the leaves a new form, in which it is soluble and transferable to all parts of the plant. In this new form the carbon aids in constituting several new products; these are named sugar when they possess a sweet taste, gum or mucilage when tasteless, and excrementitious matters when expelled by the roots.

Hence it is evident that the quantity and quality of the substances generated by the vital processes of a plant will vary according to the proportion of the different kinds of food with which it is supplied. The developement of every part of a plant in a free and uncultivated state depends on the amount and nature of the food afforded to it by the spot on which it grows. A plant is developed on the most sterile and unfruitful soil as well as on the most luxuriant and fertile, the only difference which can be observed being in its height and size, in the number of its twigs, branches, leaves, blossoms, and fruit. Whilst the individual organs of a plant increase on a fertile soil, they diminish on another where those substances which are necessary for their formation are not so bountifully supplied; and the proportion of the constituents which contain nitrogen and of those which do not in plants varies with the amount of nitrogenous matters in their food.

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* Children fed upon arrow-root, salep, or indeed any kind of amylaceous food, which does not contain ingredients fitted for the formation of bones and muscles, become fat, and acquire much *embonpoint;* their limbs appear full, but they do not acquire strength, nor are their organs properly developed.

The developement of the stem, leaves, blossoms, and fruit of plants is dependent on certain conditions, the knowledge of which enables us to exercise some influence on their internal constituents as well as on their size. It is the duty of the natural philosopher to discover what these conditions are; for the fundamental principles of agriculture must be based on a knowledge of them. There is no profession which can be compared in importance with that of agriculture, for to it belongs the production of food for man and animals; on it depends the welfare and developement of the whole human species, the riches of states, and all commerce. There is no other profession in which the application of correct principles is productive of more beneficial effects, or is of greater and more decided influence. Hence it appears quite unaccountable, that we may vainly search for one leading principle in the writings of agriculturists and vegetable physiologists.

The methods employed in the cultivation of land are different in every country, and in every district; and when we inquire the causes of these differences, we receive the answer, that they depend upon circumstances. (*Les circonstances font les assolements.*) No answer could show ignorance more plainly, since no one has ever yet devoted himself to ascertain what these circumstances are. Thus also when we inquire in what manner manure acts, we are answered by the most intelligent men, that its action is covered by the veil of Isis; and when we demand further what this means, we discover merely that the excrements of men and animals are supposed to contain an incomprehensible *something* which assists in the nutrition of plants, and increases their size. This opinion is embraced without even an attempt being made to discover the component parts of manure, or to become acquainted with its nature.

In addition to the general conditions, such as heat, light, moisture, and the component parts of the atmosphere, which are necessary for the growth of all plants, certain substances are found to exercise a peculiar influence on the developement of particular families. These substances either are already contained in the soil, or are supplied to it in the form of the matters known under the general name of manure. But what does the soil contain, and what are the components of the substances used as manure? Until these points are satisfactorily determined, a rational system of agriculture cannot exist. The power and knowledge of the physiologist, of the agriculturist and chemist, must be united for the complete solution of these questions; and in order to attain this end, a commencement must be made.

The *general* object of agriculture is to produce in the most advantageous manner certain qualities, or a maximum size, in certain parts or organs of particular plants. Now, this object can be attained only by the application of those substances which we know to be indispensable to the developement of these parts or organs, or by supplying the conditions necessary to the production of the qualities desired.

The rules of a rational system of agriculture should enable us, therefore, to give to each plant that which it requires for the attainment of the object in view.

The *special* object of agriculture is to obtain an abnormal developement and production of certain parts of plants, or of certain vegetable matters, which are employed as food for man and animals, or for the purpose of industry.

The means employed for effecting these two purposes are very different. Thus the mode of culture, employed for the purpose of procuring fine pliable straw for Florentine hats, is the very opposite to that which must be adopted in order to produce a maximum of corn from the same plant. Peculiar methods must be used for the production of nitrogen in the seeds, others for giving strength and solidity to the straw, and others again must be followed when we wish to give such strength and solidity to the straw as will enable it to bear the weight of the ears.

We must proceed in the culture of plants in precisely the same manner as we do in the fattening of animals. The flesh of the stag and roe, or of wild animals in general, is quite devoid of fat, like the muscular flesh of the Arab; or it contains only small quantities of it. The production of flesh and fat may be artificially increased; all domestic animals, for example, contain much fat. We give food to animals, which increases the activity of certain organs, and is itself capable of being transformed into fat. We add to the quantity of food, or we lessen the processes of respiration and perspiration by preventing motion. The conditions necessary to effect this purpose in birds are different from those in quadrupeds; and it is well known that charcoal powder produces such an excessive growth of the liver of a goose, as at length causes the death of the animal.

The increase or diminution of the vital activity of vegetables depends only on heat and solar light, which we have not arbitrarily at our disposal: all that we can do is to supply those substances which are adapted for assimilation by the power already present in the organs of the plant. But wha then are these substances? They may easily be detected by the examination of a soil, which is always fertile in given cosmical and atmospheric conditions; for it is evident, that the knowledge of its state and composition must enable us to discover the circumstances under which a sterile soil may be rendered fertile. It is the duty of the chemist to explain the composition of a fertile soil, but the discovery of its proper state or condition belongs to the agriculturist; our present business lies only with the former.

Arable land is originally formed by the crumbling of rocks, and its properties depend on the nature of their principal component parts. Sand, clay, and lime, are the names given to the principal constituents of the different kinds of soil.

Pure sand and pure limestones, in which there are no other inorganic substances except siliceous earth, carbonate or silicate of lime, form absolutely barren soils. But argillaceous earths form always a part of fertile soils. Now from whence come the argillaceous earths in arable land, what are their constituents, and what part do they play in favouring vegetation? They are produced by the disintegration of aluminous minerals by the action of the weather; the common potash and soda felspars, Labrador spar, mica, and the zeolites, are the most common aluminous earths, which undergo this change. These minerals are found mixed with other substances in granite, gneiss, mica-slate, porphyry, clay-slate, grauwacke, and the volcanic rocks, basalt, clinkstone, and lava. In the grauwacke, we have pure quartz, clay-slate, and lime; in the sandstones, quartz and loam. The transition limestone and the dolomites contain an intermixture of clay, felspar, porphyry, and clay-slate; and the mountain limestone is remarkable for the quantity of argillaceous earths which it contains. Jura limestone contains 3—20, that of the Wurtemberg Alps 45—50 per cent. of these earths. And in the ***muschelkalk*** and the ***calcaire grossier*** they exist in greater or less quantity.

It is known, that the aluminous minerals are the most widely diffused on the surface of the earth, and as we have already mentioned, all fertile soils, or soils capable of culture, contain alumina as an invariable constituent. There must, therefore, be something in aluminous earth which enables it to exercise an influence on the life of plants, and to assist in their developement. The property on which this depends is that of its invariably containing potash and soda.

Alumina exercises only an indirect influence on vegetation, by its power of attracting and retaining water and ammonia; it is itself very rarely found in the ashes of plants,* but silica is always present, having in most places entered the plants by means of alkalies. In order to form a distinct conception of the quantities of alkalies in aluminous minerals, it must be remembered that felspar contains 17¾ per cent. of potash, albite 11·43 per cent. of soda, and mica 3—5 per cent.; and that zeolite contains 13—16 per cent. of both alkalies taken together. The late analyses of Ch. Gmelin, Lowe, Fricke, Meyer, and Redtenbacher, have also shown, that basalt contains from ¾ to 3 per cent. of potash, and from 5—7 per cent. of soda, that clay slate contains from 2·75—3·31 per cent. of potash, and loam from 1½—4 per cent. of potash.

If, now, we calculate from these data, and from the specific weights of the different substances, how much potash must be contained in a layer of soil, which has been formed by the disintegration of 26,910 square feet (1 Hessian acre) of one of these rocks to the depth of 20 inches, we find that a soil of

Felspar	contains	. . . . .			1,675,000	lbs.
Clink-stone	“	from	220,000	to	440,000	“
Basalt	“	“	52,300	“	82,600	“
Clay-slate	“	“	110,000	“	220,000	“
Loam,	“	“	95,000	“	330,000	“

Potash is present in all clays; according to Fuchs, it is contained even in marl; it has been found in all the argillaceous earths in which it has been sought. The fact that they contain potash may be proved in the clays of the transition and stratified mountains, as well as in the recent formations surrounding Berlin, by simply digesting them with sulphuric acid, by which process alum is formed. (Mitscherlich.) It is well known also to all manufacturers of alum, that the leys contain a certain quantity of this salt ready formed, the potash of which has its origin from the ashes of the stone and brown coal, which contain much argillaceous earth.

When we consider this extraordinary distribution of potash over the surface of the earth, is it reasonable to have recourse to the idea, that the presence of this alkali in plants is due to the generation of a metallic oxide by a peculiar organic process from the component parts of the atmosphere? This opinion found adherents even after the method of detecting potash in soils was known, and suppositions of the same kind may be found even in the writings of some physiologists of the present day. Such opinions belong properly to the time when flint was conceived to be a product of chalk, and when every thing which appeared incomprehensible on account of not having been investigated, was explained by assumptions far more incomprehensible.

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* Alumina is generally supposed to be a common ingredient of the ashes of plants, and it is very frequently stated in the results of their analyses; but in most cases it has been mistaken for phosphate of magnesia, or phosphate of alumina, with which it has many properties in common, and from which it cannot be distinguished without much care and attention.—Ed.

A thousandth part of loam mixed with the quartz in new red sandstone, or with the lime in the different limestone formations, affords as much potash to a soil only twenty inches in depth as is sufficient to supply a forest of pines growing upon it for a century. A single cubic foot of felspar is sufficient to supply a wood, covering a surface of 26,910 square feet, with the potash required for five years.

Land of the greatest fertility contains argillaceous earths and other disintegrated minerals with chalk and sand in such a proportion as to give free access to air and moisture. The land in the vicinity of Vesuvius may be considered as the type of a fertile soil, and its fertility is greater or less in different parts, according to the proportion of clay or sand which it contains.

The soil which is formed by the disintegration of lava, cannot possibly, on account of its origin, contain the smallest trace of vegetable matter, and yet it is well known that when the volcanic ashes have been exposed for some time to the influence of air and moisture, a soil is gradually formed in which all kinds of plants grow with the greatest luxuriance. This fertility is owing to the alkalies which are contained in the lava, and which by exposure to the weather are rendered capable of being absorbed by plants. Thousands of years have been necessary to convert stones and rocks into the soil of arable land, and thousands of years more will be requisite for their perfect reduction, that is, for the complete exhaustion of their alkalies.

We see from the composition of the water in rivers, streamlets, and springs, how little rain-water is able to extract alkali from a soil, even after a term of years; this water is generally soft, and the common salt, which even the softest invariably contains, proves that those alkaline salts, which are carried to the sea by rivers and streams, are returned again to the land by wind and rain.

Nature itself shows us what plants require at the commencement of the developement of their germs and first radicle fibres. Bequerel has shown that the *graminæ, leguminosæ, cruciferæ, cichoraceæ, umbelliferæ, coniferæ, and cucurbitaceæ* emit acetic acid during germination. A plant which has just broken through the soil, and a leaf just burst open from the bud, furnish ashes by incineration, which contain as much, and generally more, of alkaline salts than at any period of their life. (De Saussure.) Now we know also, from the experiments of Bequerel, in what manner these alkaline salts enter young plants; the acetic acid formed during germination is diffused through the wet or moist soil, becomes saturated with lime, magnesia, and alkalies, and is again absorbed by the radicle fibres in the form of neutral salts. After the cessation of life, when plants are subjected to decomposition by means of decay and putrefaction, the soil receives again that which had been extracted from it.

Let us suppose that a soil has been formed by the action of the weather on the component parts of granite, grauwacke, mountain limestone, or porphyry, and that nothing has vegetated on it for thousands of years. Now this soil would become a magazine of alkalies in a condition favourable for their assimilation by the roots of plants.

The interesting experiments of Struve have proved that water impregnated with carbonic acid decomposes rocks which contain alkalies, and then dissolves a part of the alkaline carbonates. It is evident that plants also, by producing carbonic acid during their decay, and by means of the acids which exude from their roots in the living state, contribute no less powerfully to destroy the coherence of rocks. Next to the action of air, water, and change of temperature, plants themselves are the most powerful agents in effecting the disintegration of rocks.

Air, water, and the change of temperature prepare the different species of rocks for yielding to plants the alkalies which they contain. A soil which has been exposed for centuries to all the influences which affect the disintegration of rocks, but from which the alkalies have not been removed, will be able to afford the means of nourishment to those vegetables which require alkalies for its growth during many years; but it must gradually become exhausted, unless those alkalies which have been removed are again replaced; a period, therefore, will arrive when it will be necessary to expose it from time to time to a farther disintegration, in order to obtain a new supply of soluble alkalies. For small as is the quantity of alkali which plants require, it is nevertheless quite indispensable for their perfect developement. But when one or more years have elapsed without any alkalies having been extracted from the soil, a new harvest may be expected.

The first colonists of Virginia found a country the soil of which was similar to that mentioned above; harvests of wheat and tobacco were obtained for a century from one and the same field, without the aid of manure; but now whole districts are converted into unfruitful pasture-land, which without manure produces neither wheat nor tobacco. From every acre of this land there were removed in the space of one hundred years 12,000 lbs. of alkalies in leaves, grain, and straw; it became unfruitful, therefore, because it was deprived of every particle of alkali, which had been reduced to a soluble state, and because that which was rendered soluble again in the space of one year was not sufficient to satisfy the demands of the plants. Almost all the cultivated land in Europe is in this condition; fallow is the term applied to land left at rest for farther disintegration. It is the greatest possible mistake to suppose that the temporary diminution of fertility in a soil is owing to the loss of humus; it is the mere consequence of the exhaustion of the alkalies.

Let us consider the condition of the country around Naples, which is famed for its fruitful corn-land; the farms and villages are situated from eighteen to twenty-four miles distant from one another, and between them there are no roads, and consequently no transportation of manure. Now corn has been cultivated on this land for thousands of years, without any part of that which is annually removed from the soil being artificially restored to it. How can any influence be ascribed to humus under such circumstances, when it is not even known whether humus was ever contained in the soil?

The method of culture in that district completely explains the permanent fertility. It appears very bad in the eyes of our agriculturists, but there it is the best plan which could be adopted. A field is cultivated once every three years, and is in the intervals allowed to serve as a sparing pasture for cattle. The soil experiences no change in the two years during which it there lies fallow, farther than that it is exposed to the influence of the weather, by which a fresh portion of the alkalies contained in it are again set free or rendered soluble. The animals fed on these fields yield nothing to these soils which they did not formerly possess. The weeds upon which they live spring from the soil, and that which they return to it as excrement must always be less than that which they extract. The fields, therefore, can have gained nothing from the mere feeding of cattle upon them; on the contrary, the soil must have lost some of its constituents.

Experience has shown in agriculture that wheat should not be cultivated after wheat on the same soil, for it belongs with tobacco to the plants which exhaust a soil. But if the humus of a soil gives it the power of producing corn, how happens it that wheat does not thrive in many parts of Brazil, where the soils are particularly rich in this substance, or in our own climate, in soils formed of mouldered wood; that its stalk under these circumstances attains no strength, and droops prematurely? The cause is this, that the strength of the stalk is due to silicate of potash, and that the corn requires phosphate of magnesia, neither of which substances a soil of humus can afford, since it does not contain them; the plant may, indeed, under such circumstances, become an herb, but will not bear fruit.

Again, how does it happen that wheat does not flourish on a sandy soil, and that a calcareous soil is also unsuitable for its growth, unless it be mixed with a considerable quantity of clay?[*] It is because these soils do not contain alkalies in sufficient quantity, the growth of wheat being arrested by this circumstance, even should all other substances be presented in abundance.

It is not mere accident that only trees of the fir tribe grow on the sandstone and limestone of the Carpathian mountains and the Jura, whilst we find on soils of gneiss, mica-slate, and granite in Bavaria, of clinkstone on the Rhone, of basalt in Vogelsberge, and of clay-slate on the Rhine and Eifel, the finest forests of other trees, which cannot be produced on the sandy or calcareous soils upon which pines thrive. It is explained by the fact that trees, the leaves of which are renewed annually, require for their leaves six to ten times more alkalies than the fir-tree or pine, and hence when they are placed in soils in which alkalies are contained in very small quantity, do not attain maturity.[*] When we see such trees growing on a sandy or calcareous soil—the red-beech, the service-tree, and the wild-cherry for example, thriving luxuriantly on lime stone, we may be assured that alkalies are present in the soil, for they are necessary to their existence. Can we, then, regard it as remarkable that such trees should thrive in America, on those spots on which forests of pines which have grown and collected alkalies for centuries, have been burnt, and to which the alkalies are thus at once restored; or that the *Spartium scoparium*, *Erysimum latifolium*, *Blitum capitatum*, *Senecio viscosus*, plants remarkable for the quantity of alkalies contained in their ashes, should grow with the greatest luxuriance on the localities of conflagrations?[†]

Wheat will not grow on a soil which has produced wormwood, and *vice versâ*, wormwood does not thrive where wheat has grown, because they are mutually prejudicial by appropriating the alkalies of the soil.

One hundred parts of the stalks of wheat yield 15·5 parts of ashes (H. Davy;) the same quantity of the dry stalks of barley,

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[*] In consequence of these remarks in the former edition of this work, Professor Wöhler of Göttingen has made several accurate analyses of different kinds of limestone belonging to the secondary and tertiary formations. He obtained the remarkable result, that all those limestones, by the disintegration of which soils adapted for the culture of wheat are formed, invariably contain a certain quantity of potash. The same observation has also recently been made by M. Kuhlman of Lille. The latter observed that the efflorescence on the mortar of walls consists of the carbonates of soda and potash.

[*] One thousand parts of the dry leaves of oaks yielded 55 parts of ashes, of which 24 parts consisted of alkalies soluble in water; the same quantity of pine-leaves gave only 29 parts of ashes, which contain 4.6 parts of soluble salts. (De Saussure.)

[†] After the great fire in London, large quantities of the *Erysimum latifolium* where observed growing on the spots where a fire had taken place. On a similar occasion the *Blitum capitatum* was seen at Copenhagen, the *Senecio viscosus* in Nassau, and the *Spartium scoparium* in Languedoc. After the burnings of forests of pines in North America, poplars grew on the same soil.

8·54 parts (Schrader;) and one hundred parts of the stalks of oats, only 4·42;—the ashes of all these are of the same composition.

We have in these facts a clear proof of what plants require for their growth. Upon the same field, which will yield only one harvest of wheat, two crops of barley and three of oats may be raised.

All plants of the grass kind require silicate of potash. Now this is conveyed to the soil, or rendered soluble in it by the irrigation of meadows. The *equisetaceæ*, the reeds and species of cane, for example, which contain such large quantities of siliceous earth, or silicate of potash, thrive luxuriantly in marshes, in argillaceous soils, and in ditches, streamlets, and other places where the change of water renews constantly the supply of dissolved silica. The amount of silicate of potash removed from a meadow in the form of hay is very considerable. We need only call to mind the melted vitreous mass found on a meadow between Manheim and Heidelberg after a thunder-storm. This mass was at first supposed to be a meteor, but was found on examination (by Gmelin) to consist of silicate of potash; a flash of lightning had struck a stack of hay, and nothing was found in its place except the melted ashes of the hay.

Potash is not the only substance necessary for the existence of most plants; indeed it has been already shown that the potash may be replaced in many cases by soda, magnesia, or lime; but other substances besides alkalies are required to sustain the life of plants.

Phosphoric acid has been found in the ashes of all plants hitherto examined, and always in combination with alkalies or alkaline earths.[*] Most seeds contain certain quantities of phosphates. In the seeds of different kinds of corn particularly, there is abundance of phosphate of magnesia.

Plants obtain their phosphoric acid from the soil. It is a constituent of all land capable of cultivation, and even the heath at Lüneburg contains it in appreciable quantity. Phosphoric acid has been detected also in all mineral waters in which its presence has been tested; and in those in which it has not been found it has not been sought for. The most superficial strata of the deposits of sulphuret of lead (*galena*) contain crystallised phosphate of lead (*green-lead ore*;) clay-slate, which forms extensive strata, is covered in many places with crystals of phosphate of alumina (*Wavellite*;) all its fractured surfaces are overlaid with it. Phosphate of lime (*Apatite*) is found even in the volcanic boulders on the Laacher See in the Eifel, near Andernach.[*]

The soil in which plants grow furnishes them with phosphoric acid, and they in turn yield it to animals, to be used in the formation of their bones, and of those constituents of the brain which contain phosphorus. Much more phosphorus is thus afforded to the body than it requires, when flesh, bread, fruit, and husks of grain are used for food, and this excess is eliminated in the urine and the solid excrements. We may form an idea of the quantity of phosphate of magnesia contained in grain, when we consider that the concretions in the cæcum of horses consist of phosphate of magnesia and ammonia, which must have been obtained from the hay and oats consumed as food. Twenty-nine of these stones were taken after death from the rectum of a horse belonging to a miller, in Eberstadt, the total weight of which amounted to 3 lbs.; and Dr. F. Simon has lately described a similar concretion found in the horse of a carrier, which weighed 1½ lb.

It is evident that the seeds of corn could not be formed without phosphate of magnesia, which is one of their invariable constituents; the plant could not under such circumstances reach maturity.

Some plants, however, extract other matters from the soil besides silica, potash, and phosphoric acid, which are essential constituents of the plants ordinarily cultivated.[†] These other matters, we must suppose, supply, in part at least, the place and perform the functions of the substances just named. We may thus regard common salt, sulphate of potash, nitre, chloride of potassium, and other matters, as necessary constituents of several plants.

Clay-slate contains generally small quantities of oxide of copper; and soils formed from micaceous schist contain some metallic fluorides. Now, small quantities of these substances also are absorbed into plants, although we cannot affirm that they are necessary to them.

It appears that in certain cases flouride of calcium may take the place of phosphate of lime in the bones and teeth; at least it is impossible otherwise to explain its constant presence in the bones of antediluvian animals, by which they are distinguished from those of a later period. The bones of human skulls found at Pompeii contain as much fluoric acid as those of animals of a former world, for if they be placed in a state of powder in glass vessels, and digested with sulphuric acid, the interior of the vessel will, after twenty-four hours, be found powerfully corroded (Liebig;) whilst the bones and teeth of animals of the present day contain only traces of it. (Berzelius.)

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[*] Professor Connall was lately kind enough to show me about half an ounce of a saline powder, which had been taken from an interstice in the body of a piece of teak timber. It consisted essentially of phosphate of lime, with small quantities of carbonate of lime and phosphate of magnesia. This powder had been sent to Sir David Brewster from India, with the assurance that it was the same substance which usually is found in the hollows of teak timber. It has long been known that silica, in the form of *tabasheer*, is secreted by the bamboo; but I am not aware that phosphates have been found in the same condition. Without more precise information, we must therefore suppose that they are left in the hollows by the decay of the wood. Decay is a slow process of combustion, and the incombustible ashes must remain after the organic matter has been consumed. But if this explanation be correct, the wood of the teak-tree must contain an enormous quantity of earthy phosphates.—Ed.

[*] See the analyses of soils in the Appendix.

[†] For more minute information regarding soils see the supplementary chapter at the end of Part 1.

De Saussure remarked that plants require quantities of the component parts of soils in different stages of their developement; an observation of much importance in considering the growth of plants. Thus wheat yielded 79-1000 of ashes a month before blossoming, 54-1000 while in blossom, and 33·1000 after the ripening of the seeds. It is therefore evident that wheat, from the time of its flowering, restores a part of its organic constituents to the soil, although the phosphate of magnesia remains in the seeds.

The fallow-time, as we have already shown, is that period of culture during which land is exposed to a progressive disintegration by means of the influence of the atmosphere, for the purpose of rendering a certain quantity of alkalies capable of being appropriated by plants.

Now, it is evident, that the careful tilling of fallow-land must increase and accelerate this disintegration. For the purpose of agriculture, it is quite indifferent, whether the land is covered with weeds, or with a plant which does not abstract the potash inclosed in it. Now many plants in the family of the *leguminosæ* are remarkable on account of the small quantity of alkalies or salts in general which they contain; the Windsor bean (*Vicia Faba,*) for example, contains no free alkalies, and not one per cent. of the phosphates of lime and magnesia. (Einhof.) The bean of the kidney-bean (*Phaseolus vulgaris*) contains only traces of salts. (Braconnot.) The stem of lucerne (*Medicago sativa*) contains only 0.83 per cent., that of the lentil (*Ervum Lens*) only 0.57 of phosphate of lime with albumen. (Crome.) Buck-wheat dried in the sun yields only 0.681 per cent. of ashes, of which 0.09 parts are soluble salts. (Zenneck.)* These plants belong to those which are termed fallow-crops, and the cause wherefore they do not exercise any injurious influence on corn which is cultivated immediately after them is, that they do not extract the alkalies of the soil, and only a very small quantity of phosphates.

It is evident that two plants growing beside each other will mutually injure one another, if they withdraw the same food from the soil. Hence it is not surprising that the wild chamomile (*Matricaria Chamomilla*) and Scotch-broom (*Spartium Scoparium*) impede the growth of corn, when it is considered that both yield from 7 to 7.43 per cent. of ashes, which contain $\frac{8}{10}$ of carbonate of potash. The darnel and the flea-bane (*Erigeron acre*) blossom and bear fruit at the same time as corn, so that when growing mingled with it, they will partake of the component parts of the soil, and in proportion to the vigour of their growth, that of the corn must decrease; for what one receives, the others are deprived of. Plants will, on the contrary, thrive beside each other, either when the substances necessary for their growth which they extract from the soil are of different kinds, or when they themselves are not both in the same stages of developement at the same time.

On a soil, for example, which contains potash, both wheat and tobacco may be reared in succession, because the latter plant does not require phosphates, salts which are invariably present in wheat, but requires only alkalies, and food containing nitrogen.

According to the analysis of Posselt and Riemann, 10,000 parts of the leaves of the tobacco-plant contain 16 parts of phosphate of lime, 8.8 parts of silica, and no magnesia; whilst an equal quantity of wheat straw contains 47.3 parts, and the same quantity of the grain of wheat 99.45 parts of phosphates. (De Saussure.)

Now, if we suppose that the grain of wheat is equal to half the weight of its straw, then the quantity of phosphates extracted from a soil by the same weights of wheat and tobacco must be as 97.7 : 16. This difference is very considerable. The roots of tobacco, as well as those of wheat, extract the phosphates contained in the soil, but they restore them again, because they are not essentially necessary to the developement of the plant.

CHAPTER VIII.

ON THE ALTERNATION OF CROPS.

T has long since been found by experience, that the growth of annual plants is rendered imperfect, and their crops of fruit or herbs less abundant, by cultivating them in successive years on the same soil, and that, in spite of the loss of time, a greater quantity of grain is obtained when a field is allowed to lie uncultivated for a year. During this interval of rest, the soil, in a great measure, regains its original fertility.

It has been further observed, that certain plants, such as peas, clover, and flax, thrive on the same soil only after a lapse of years; whilst others, such as hemp, tobacco, *helianthus tuberosus,* rye, and oats may be cultivated in close succession when proper manure is used. It has also been found, that several of these plants improve the soil, whilst others, and these are the most numerous, impoverish or exhaust it. Fallow turnips, cabbage, beet, spelt, summer and winter barley, rye and oats, are considered to belong to the class which impoverish a soil; whilst by wheat, hops, madder, late turnips, hemp, poppies, teasel, flax, weld, and licorice, it is supposed to be entirely exhausted.

The excrements of man and animals have been employed from the earliest times for the purpose of increasing the fertility of soils; and it is completely established by all experience, that they restore certain constituents to the soil, which are removed with the roots, fruit or grain, or entire plants grown upon it.

But it has been observed that the crops are not always abundant in proportion to the quantity of manure employed, even although it may have been of the most powerful kind; that the produce of many plants, for example, diminishes, in spite of the apparent replacement by manure of the substances removed from the soil, when they are cultivated on the same field for several years in succession.

On the other hand it has been remarked, that a field which has become unfitted for a certain kind of plants was not on that account unsuited for another; and upon this observation, a system of agriculture has been gradually founded, the principal object of which is to obtain the greatest possible produce with the least expense of manure.

Now it was deduced from all the foregoing facts that plants require for their growth different constituents of soil, and it was very soon perceived, that an alternation of the plants cultivated maintained the fertility of a soil quite as well as leaving it at rest or fallow. It was evident that all plants must give back to the soil in which they grow different proportions of certain substances, which are capable of being used as food by a succeeding generation.

But agriculture has hitherto never sought aid from chemical principles, based on the knowledge of those substances which plants extract from the soil on which they grow, and of those restored to the soil by means of manure. The discovery of such principles will be the task of a future generation, for what can be expected from the present, which recoils with seeming distrust and aversion from all the means of assistance offered it by chemistry, and which does not understand the art of making a rational application of chemical discoveries? A future generation, however, will derive incalculable advantage from these means of help.

Of all the views which have been adopted regarding the cause of the favourable effects of the alternations of crops, that proposed by M. Decandolle alone deserves to be mentioned as resting on a firm basis.

Decandolle supposes that the roots of plants imbibe soluble matter of every kind from the soil, and thus necessarily absorb a number of substances which are not adapted to the purposes of nutrition, and must subsequently be expelled by the roots, and returned to the soil as excrements. Now, as excrements cannot be assimilated by the plant which ejected them, the more of these matters which the soil contains, the more unfertile must it be for the plants of the same species. These excrementitious matters may, however, still be capable of assimilation by another kind of plants, which would thus remove them from the soil, and render it again fertile for the first. And if the plants last grown also expel substances from their roots, which can be appropriated as food by the former, they will improve the soil in two ways.

Now a great number of facts appear at first sight to give a high degree of probability to this view. Every gardener knows that a fruit-tree cannot be made to grow on the same spot where another of the same species has stood; at least not until after a lapse of several years. Before new vine-stocks are planted in a vineyard from which the old have been rooted out, other plants are cultivated on the soil for several years. In connexion with this it has been observed, that several plants thrive best when growing beside one another; and on the contrary, that others mutually prevent each other's developement. Whence it was concluded, that the beneficial influence in the former case depended on a mutual interchange of nutriment between the plants, and the injurious one in the latter on a poisonous action of the excrements of each on the other respectively.

A series of experiments by Macaire-Princep gave great weight to this theory. He proved beyond all doubt that many plants are capable of emitting extractive matter from their roots. He found that the excretions were greater during the night than by day (?), and that the water in which plants of the family of the *Leguminosæ* grew acquired a brown colour. Plants of the same species placed in water impregnated with these excrements were impeded in their growth, and faded prematurely, whilst, on the contrary, corn-plants grew vigorously in it, and the colour of the water diminished sensibly; so that it appeared as if a certain quantity of the excrements of the *Leguminosæ* had really been absorbed by the corn-plants. These experiments afforded, as their main result, that the characters and properties of the ex

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* The small quantity of phosphates which the seeds of the lentils, beans, and peas contain, must be the cause of their small value as articles of nourishment, since they surpass all other vegetable food in the quantity of nitrogen which enters into their composition. But as the component parts of the bones (phosphate of lime and magnesia) are absent, they satisfy the appetite without increasing the strength. The following is an analysis of lentils (Playfair.) 6.092 grammes lost 0.972 grammes of water at 212°. 0.566 grammes, burned with oxide of copper, gave 0.910 grammes carbonic acid and 0.336 grammes of water. The lentils on combustion with oxide of copper, yielded a gas, in which the proportion of the nitrogen to the carbonic acid was as 1 to 16.

Carbon	44.45
Hydrogen	6.59
Nitrogen	6.42
Water	15.95

crements of different species of plants are different from one another, and that some plants expel excrementitious matter of an acrid and resinous character; others mild substances resembling gum. The former of these, according to Macaire-Princep, may be regarded as poisonous, the latter as nutritious.

The experiments of Macaire-Princep afford positive proof that the roots, probably of all plants, expel matters, which cannot be converted in their organism either into woody fibre, starch, vegetable albumen, or gluten, since their expulsion indicates that they are quite unfitted for this purpose. But they cannot be considered as a confirmation of the theory of Decandolle, for they leave it quite undecided whether the substances were extracted from the soil, or formed by the plant itself from food received from another source. It is certain that the gummy and resinous excrements observed by Macaire-Princep could not have been contained in the soil, and as we know that the carbon of a soil is not diminished by culture, but, on the contrary, increased, we must conclude that all excrements which contain carbon must be formed from the food obtained by plants from the atmosphere. Now, these excrements are compounds, produced in consequence of the transformations of the food, and of the new forms which it assumes by entering into the composition of the various organs.

M. Decandolle's theory is properly a modification of an earlier hypothesis, which supposed that the roots of different plants extracted different nutritive substances from the soil, each plant selecting that which was exactly suited for its assimilation. According to this hypothesis, the matters incapable of assimilation are not extracted from the soil, whilst M. Decandolle considers that *they are returned* to it in the form of excrements. Both views explain how it happens that after corn, corn cannot be raised with advantage, nor after peas, peas; but they do not explain how a field is improved by lying fallow, and this in proportion to the care with which it is tilled and kept free from weeds; nor do they show how a soil gains carbonaceous matter by the cultivation of certain plants, such as lucerne and sainfoin.

Theoretical considerations on the process of nutrition, as well as the experience of all agriculturists, so beautifully illustrated by the experiments of Macaire-Princep, leave no doubt that substances are excreted from the roots of plants, and that these matters form the means by which the carbon received from humus in the early period of their growth is restored to the soil. But we may now inquire whether these excrements, in the state in which they are expelled, are capable of being employed as food by other plants.

The excrements of a carnivorous animal contain no constituents fitted for the nourishment of another of the same species; but it is possible that an herbivorous animal, a fish, or a fowl, might find in them undigested matters capable of being digested in their organism, from the very circumstance of their organs of digestion having a different structure. This is the only sense in which we can conceive that the excrements of one animal could yield matter adapted for the nutrition of another.

A number of substances contained in the food of animals pass through their alimentary organs without change, and are expelled from the system; these are excrements but not excretions. Now a part of such excrementitious matter might be assimilated in passing through the digestive apparatus of another animal. The organs of secretion form combinations of which only the elements were contained in the food. The production of these new compounds is a consequence of the changes which the food undergoes in becoming chyle and chyme, and of the further transformations to which these are subjected by entering into the composition of the organism. These matters, likewise, are eliminated in the excrements, which must therefore consist of two different kinds of substances, namely, of the indigestible constituents of the food, and of the new compounds formed by the vital process. The latter substances have been produced in consequence of the formation of fat, muscular fibre, cerebral and nervous substance, and are quite incapable of being converted into the same substances in any other animal organism.

Exactly similar conditions must subsist in the vital processes of plants. When substances which are incapable of being employed in the nutrition of a plant exist in the matter absorbed by its roots, they must be again returned to the soil. Such excrements might be serviceable and even indispensable to the existence of several other plants. But substances that are formed in a vegetable organism during the process of nutrition, which are produced, therefore, in consequence of the formation of woody fibre, starch, albumen, gum, acids, &c., cannot again serve in any other plants to form the same constituents of vegetables.

The consideration of these facts enables us to distinguish the difference between the views of Decandolle and those of Macaire-Princep. The substances which the former physiologist viewed as excrements, belonged to the soil; they were undigested matters, which although not adapted for the nutrition of one plant might yet be indispensable to another. Those matters, on the contrary, designated as excrements by Macaire-Princep, could only in one form serve for the nutrition of vegetables. It is scarcely necessary to remark that this excrementitious matter must undergo a change before another season. During autumn and winter it begins to suffer a change from the influence of air and water; its putrefaction, and a length, by continued contact with the air, which tillage is the means of procuring, its decay are effected; and at the commencement of spring it has become converted, either in whole or in part, into a substance which supplies the place of humus, by being a constant source of carbonic acid.

The quickness with which this decay of the excrements of plants proceeds depends on the composition of the soil, and on its greater or less porosity. It will take place very quickly in a calcareous soil: for the power of organic excrements to attract oxygen and to putrefy is increased by contact with the alkaline constituents, and by the general porous nature of such kinds of soil, which freely permit the access of air. But it requires a longer time in heavy soils consisting of loam or clay.

The same plants can be cultivated with advantage on one soil after the second year, but in others not until the fifth or ninth, merely on account of the change and destruction of the excrements, which have an injurious influence on the plants being completed in the one, in the second year; in the others, not until the ninth.

In some neighbourhoods clover will not thrive till the sixth year, in others not till the twelfth; flax in the second or third year. All this depends on the chemical nature of the soil, for it has been found by experience that in those districts where the intervals at which the same plants can be cultivated with advantage are very long, the time cannot be shortened even by the use of the most powerful manures. The destruction of the peculiar excrements of one crop must have taken place before a new crop can be produced.

Flax, peas, clover, and even potatoes, are plants the excrements of which, in argillaceous soils, require the longest time for their conversion into humus; but it is evident that the use of alkalies and burnt lime, or even small quantities of ashes which have not been lixiviated, must enable a soil to permit the cultivation of the same plants in a much shorter time.

A soil lying fallow owes its earlier fertility, in part, to the destruction or conversion into humus of the excrements contained in it, which is effected during the fallow season, at the same time that the land is exposed to a farther disintegration.

In the soils in the neighbourhood of the Rhine and Nile, which contain much potash, and where crops can be obtained in close succession from the same field, the fallowing of the land is superseded by the inundation; the irrigation of meadows effects the same purpose. It is because the water of rivers and streams contains oxygen in solution that it effects the most complete and rapid putrefaction of the excrements contained in the soil which it penetrates, and in which it is continually renewed. If it was the water alone which produced this effect, marshy meadows should be most fertile. Hence it is not sufficient in irrigating meadows to convert them into marshes, by covering for several months their surface with water, which is not renewed; for the advantage of irrigation consists principally in supplying oxygen to the roots of plants. The quantity of water necessary for this purpose is very small, so that it is sufficient to cover the meadow with a very thin layer, if this be frequently renewed.

The cultivation of meadows forms one of the most important branches of rural economy. It contributes materially to the prosperity of the agriculturist by increasing his stock of cattle, and consequently by furnishing him with manure, which may be applied to the augmentation of his crops. Indeed, the great progress which has been made in Germany in the improvement of cattle is mainly attributable to the attention which is devoted in that country to the culture of meadows. The environs of Siegin, in Nassau, are particularly famed in this respect, and every year a large number of young farmers repair to it, for the purpose of studying this branch of agriculture *in situ*. In that district the culture of grass has attained such great perfection, that the produce of their meadow-land far exceeds that obtained in any other part of Germany. This is effected simply by preparing the ground in such a manner as to enable it to be irrigated both in spring and in autumn. The surface of the soil is fitted to suit the locality, and the quantity of water which can be commanded. Thus if the meadows be situated upon a declivity, banks of from one to two feet in height are raised at short distances from each other. The water is admitted by small channels upon the most elevated bank, and allowed to discharge itself over the sides in such a manner as to run upon the bank situated below. The grass grown upon meadows irrigated in this way is three or four times higher than that obtained from fields which are covered with water that is deprived of all egress and renewal.

It follows from what has preceded that the advantage of the alternation of crops is owing to two causes.

A fertile soil ought to afford to a plant all the inorganic bodies indispensable for its existence in sufficient quantity and in such condition as allows their absorption.

All plants require alkalies, which are contained in some, in the *Gramineæ* for example, in the form of silicates; in others, in that of tartrates, citrates, acetates, or oxalates.

When these alkalies are in combination with silicic acid, the ashes obtained by the incineration of the plant contain no carbonic acid; but when they are united with organic acids, the addition of a mineral acid to their ashes causes an effervescence.

A third species of plants requires phosphate of lime, another phosphate of magnesia, and several do not thrive without carbonate of lime.

Silicic acid is the first solid substance taken up by plants; it appears to be the material from which the formation of the wood takes its origin, acting like a grain of sand around which the first crystals form in a solution of a salt which is in the act of crystallising. Silicic acid appears to perform the functions of woody fibre in the *Equisetaceæ* and bamboos,* just as the crystalline salt, oxalate of lime, does in many of the lichens.

When we grow in the same soil for several years in succession different plants, the first of which leaves behind that which the second, and the second that which the third may require, the soil will be a fruitful one for all the three kinds of produce. If the first plant, for example, be wheat, which consumes the greatest part of the silicate of potash in a soil, whilst the plants which succeed it are of such a kind as require only small quantities of potash, as is the case with *Leguminosæ*, turnips, potatoes, &c., the wheat may be again sowed with advantage after the fourth year; for during the interval of three years the soil will, by the action of the atmosphere, be rendered capable of again yielding silicate of potash in sufficient quantity for the young plants.

The same precaution must be observed with regard to the other inorganic constituents, when it is desired to grow different plants in succession on the same soil: for a successive growth of plants which extract the same component parts, must gradually render it incapable of producing them. Each of these plants during its growth returns to the soil a certain quantity of substances containing carbon, which are gradually converted into humus, and are for the most part equivalent to as much carbon as the plants had formerly extracted from the soil in a state of carbonic acid. But although this is sufficient to bring many plants to maturity, it is not enough to furnish their different organs with the greatest possible supply of nourishment. Now the object of agriculture is to produce either articles of commerce, or food for man and animals; but a maximum of produce in plants is always in proportion to the quantity of nutriment supplied to them in the first stage of their developement.

The nutriment of young plants consists of carbonic acid, contained in the soil in the form of humus, and of nitrogen in the form of ammonia, both of which must be supplied to the plants, if the desired purpose is to be accomplished. The formation of ammonia cannot be effected on cultivated land, but humus may be artificially produced; and this must be considered as an important object in the alternation of crops, and as the second reason of its peculiar advantages.

The sowing of a field with fallow plants, such as clover, rye, buck-wheat, &c., and the incorporation of plants, when nearly at blossom, with the soil, affect this supply of humus in so far, that young plants subsequently growing in it find, at a certain period of their growth, a maximum of nutriment, that is, matter in the process of decay.

The same end is obtained, but with much greater certainty, when the field is planted with sainfoin or lucerne.* These plants are remarkable on account of the great ramification of their roots, and strong developement of their leaves, and for requiring only a small quantity of inorganic matter. Until they reach a certain period of their growth, they retain all the carbonic acid and ammonia which may have been conveyed to them by rain and the air, for that which is not absorbed by the soil is appropriated by the leaves; they also possess an extensive four or six-fold surface, capable of assimilating these bodies, and of preventing the volatilization of the ammonia from the soil, by completely covering it in.

An immediate consequence of the production of the green principle of the leaves, and of their remaining component parts, as well as those of the stem, is the equally abundant excretion of organic matters into the soil from the roots.

The favourable influence which this exercises on the land, by furnishing it with matter capable of being converted into humus, lasts for several years, but barren spots gradually appear after the lapse of some time. Now it is evident that, after from six to seven years, the ground must become so impregnated with excrements that every fibre of the root will be surrounded with them. As they remain for some time in a soluble condition, the plants must absorb part of them and suffer injurious effects in consequence, because they are not capable of assimilation. When such a field is observed for several years, it is seen that the barren spots are again covered with vegetation, (the same plants being always supposed to be grown,) whilst new spots become bare and apparently unfruitful, and so on alternately. The causes which produce this alternate barrenness and fertility in the different parts of the land are evident. The excrements upon the barren spots receiving no new addition, and being subjected to the influence of air and moisture, they pass into putrefaction, and their injurious influence ceases. The plants now find those substances which formerly prevented their growth removed, and in their place meet with humus, that is, vegetable matter in the act of decay.

We can scarcely suppose a better means of producing humus than by the growth of plants, the leaves of which are food for animals; for they prepare the soil for plants of every other kind, but particularly for those to which, as to rape and flax, the presence of humus is the most essential condition of growth.

The reasons why this interchange of crops is so advantageous—the principles which regulate this part of agriculture, are, therefore, the artificial production of humus, and the cultivation of different kinds of plants upon the same field, in such an order of succession, that each shall extract only certain components of the soil, whilst it leaves behind or restores those which a second or third species of plant may require for its growth and perfect developement.

Now, although the quantity of humus in a soil may be increased to a certain degree by an artificial cultivation, still, in spite of this, there cannot be the smallest doubt that a soil must gradually lose those of its constituents which are removed in the seeds, roots, and leaves of the plants raised upon it. The fertility of a soil cannot remain unimpaired, unless we replace in it all those substances of which it has been thus deprived.

Now this is effected by *manure.*

CHAPTER IX.

OF MANURE.

When it is considered that every constituent of the body of man and animals is derived from plants, and that not a single element is generated by the vital principle, it is evident that all the inorganic constituents of the animal organism must be regarded, in some respect or other, as manure. During their life, the inorganic components of plants which are not required by the animal system, are disengaged from the organism, in the form of excrements. After their death, their nitrogen and carbon pass into the atmosphere as ammonia and carbonic acid, the products of their putrefaction, and at last nothing remains except the phosphate of lime and other salts in their bones. Now this earthy residue of the putrefaction of animals must be considered, in a rational system of agriculture, as a powerful manure for plants, because that which has been abstracted from a soil for a series of years must be restored to it, if the land is to be kept in a permanent condition of fertility.

ANIMAL MANURES.

We may now inquire whether the excrements of animals, which are employed as manure, are all of a like nature and power, and whether they, in every case, administer to the necessities of a plant by an identical mode of action. These points may easily be determined by ascertaining the composition of the animal excrements, because we shall thus learn what substances a soil really receives by their means. According to the common view, the action of solid animal excrements depends on the decaying organic matters which replace the humus, and on the presence of certain compounds of nitrogen, which are supposed to be assimilated by plants, and employed in the production of gluten and other azotised substances. But this view requires further confirmation with respect to the solid excrements of animals, for they contain so small a proportion of nitrogen, that they cannot possibly by means of it exercise any influence upon vegetation.

We may form a tolerably correct idea of the chemical nature of the animal excrement without further examination, by comparing the excrements of a dog with its food. When a dog is fed with flesh and bones, both of which consist in great part of organic substances containing nitrogen, a moist white excrement is produced, which crumbles gradually to a dry powder in the air. This excrement consists of the phosphate of lime of the bones, and contains scarcely $\frac{1}{100}$ part of its weight of foreign organic substances. The whole process of nutrition in an animal consists in the progressive extraction of all the nitrogen from the food, so that the quantity of this element found in the excrements must always be less than that contained in the nutriment. The analysis of the excrements of a horse by Macaire and Marcet proves this fact completely. The portion of excrements subjected to analysis was collected whilst fresh, and dried *in vacuo* over sulphuric acid; 100 parts of it (corresponding to from 350 to 400 parts of the dung before being dried) contained 0.8 of nitrogen. Now every one who has had experience in this kind of analysis is aware that a quantity under one per cent. cannot be determined with accuracy. We should, therefore, be estimating its proportion at a maximum, were we to consider it as equal to one-half per cent. It is certain, however, that these excrements are not entirely free from nitrogen, for they emit ammonia when digested with caustic potash.

The excrements of a cow, on combustion with oxide of copper, yielded a gas which contained one vol. of nitrogen gas, and 26.30 vol. of carbonic acid.

100 parts of fresh excrements contained

Nitrogen	0.506
Carbon	6.204
Hydrogen	0.824
Oxygen	4.818
Ashes	1.748
Water	85.900
	100.000

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* Silica is found in the joints of bamboos, in the form of small round globules, which have received the name of *Tabasheer*, and are distinguished by their remarkable optical properties.

* The alternation of crops with sainfoin and lucern is now universally adopted in Bingen and its vicinity, as well as in the Palatinate; the fields in these districts receive manure only once every nine years. In the first years after the land has been manured turnips are sown upon it, in the next following years barley, with sainfoin or lucerne; in the seventh year potatoes, in the eighth wheat, in the ninth barley; on the tenth year it is manured, and then the same rotation again takes place.

Now, according to the analysis of Boussingault, which merits the greatest confidence, hay contains one per cent. of nitrogen; consequently in the 25 lbs. of hay which a cow consumes daily, ¼ of a lb. of nitrogen must have been assimilated. This quantity of nitrogen entering into the composition of muscular fibre would yield 8·3 lbs. of flesh in its natural condition.[*] The daily increase in size of a cow is, however, much less than this quantity. We find that the nitrogen, apparently deficient, is actually contained in the milk and urine of the animal. The urine of a milch-cow contains less nitrogen than that of one which does not yield milk; and as long as a cow yields a plentiful supply of milk, it cannot be fattened. We must search for the nitrogen of the food assimilated, not in the solid, but in the liquid excrements. The influence which the former exercise on the growth of vegetables does not depend upon the quantity of nitrogen which they contain. For if this were the case, hay should possess the same influence; that is, from 20 to 25 lbs. ought to have the same power as 100 lbs. of fresh cow-dung. But this is quite opposed to all experience.

Which then are the substances in the excrements of the cow and horse which exert an influence on vegetation?

When horse-dung is treated with water, a portion of it to the amount of 3 or 3½ per cent. is dissolved, and the water is coloured yellow. The solution is found to contain phosphate of magnesia, and salts of soda, besides small quantities of organic matters.[†] The portion of the dung undissolved by the water yields to alcohol a resinous substance possessing all the characters of gall which has undergone some change; while the residue possesses the properties of saw-dust, from which all soluble matter has been extracted by water, and burns without any smell. 100 parts of the fresh dung of a horse being dried at 100° C. (212° F.) leave from 25 to 30 or 31 parts of solid substances, and contained, accordingly, from 69 to 75 parts of water. From the dried excrements, we obtain, by incineration, variable quantities of salts and earthy matters, according to the nature of the food which has been taken by the animal. Macaire and Marcet found 27 per cent. in the dung analysed by them; I obtained only 10 per cent. from that of a horse fed with chopped straw, oats, and hay. It results then that with from 3600 to 4000 lbs. of fresh horse-dung, corresponding to 100 lbs. of dry dung, we place on the land from 2484 to 3000 lbs. of water, and from 730 to 900 lbs. of vegetable matter and altered gall, and also from 100 to 270 lbs. of salt and other inorganic substances.

The latter are evidently the substances to which our attention should be directed, for they are the same which formed the component parts of the hay, straw, and oats with which the horse was fed. Their principal constituents are the phosphates of lime and magnesia, carbonate of lime and silicate of potash; the first three of these preponderated in the corn, the latter in hay.

Thus in 1000 lbs. of horse-dung, we present to a field the inorganic substances contained in 6000 lbs. of hay, or 8300 lbs. of oats (oats containing 3·1 per cent. ashes according to De Saussure.) This is sufficient to supply 1½ crop of wheat with potash and phosphates.

The excrements of cows,[*] black cattle, and sheep, contain phosphate of lime, common salt, and silicate of lime, the weight of which varies from 9 to 28 per cent., according to the fodder which the animal receives; the fresh excrements of the cow contain from 86 to 90 per cent. of water.

Human fæces have been subjected to an exact analysis by Berzelius. When fresh they contain, beside ¾ of their weight of water, nitrogen in very variable quantity, namely, in the minimum 1½, in the maximum 5 per cent. In all cases, however, they were richer in this element than the excrements of other animals. Berzelius obtained by the incineration of 100 parts of dried excrements, 15 parts of ashes, which were principally composed of the phosphates of lime and magnesia.

The following quantitative organic analysis has recently been executed for the purpose of ascertaining the proportion of carbon, nitrogen, and inorganic matter contained in fæces, in comparison with the food taken.[*] (Playfair.)

Carbon . . .	45·24
Hydrogen . . .	6·88
Nitrogen (average) . .	4·00
Oxygen . . .	30·30
Ashes . . .	13·58

The inorganic matter contained in the excrements analyzed is nearly two per cent. less than that found by Berzelius; but the proportion always varies, according to the nature of the food.

It is quite certain that the vegetable constituents of the excrements with which we manure our fields cannot be entirely without influence upon the growth of the crops on them, for they will decay, and thus furnish carbonic acid to the young plants. But it cannot be imagined that their influence is very great, when it is considered that a good soil is manured only once every six or seven years, or once every eleven or twelve years, when sainfoin or lucerne has been raised on it, that the quantity of carbon thus given to the land corresponds to only 5·8 per cent. of what is removed in the form of herbs, straw, and grain; and farther that the rain-water received by a soil contains much more carbon in the form of carbonic acid than these vegetable constituents of the manure.

The peculiar action then, of the solid excrements is limited to their inorganic constituents, which thus restore to a soil that which is removed in the form of corn, roots, or grain. When we manure land with the dung of the cow or sheep, we supply it with silicate of potash and some salts of phosphoric acid. In human fæces we give it the phosphates of lime and magnesia; and in those of the horse, phosphate of magnesia, and silicate of potash. In the straw which has served as litter, we add a farther quantity of silicate of potash and phosphates; which, if the straw be putrefied, are in exactly the same condition in which they were before being assimilated.

It is evident, therefore, that the soil of a field will alter but little, if we collect and distribute the dung carefully; a certain portion of the posphates, however, must be lost every year, being removed from the land with the corn and cattle, and this portion will accumulate in the neighbourhood of large towns. The loss thus suffered must be compensated for in a well-managed farm, and this is partly done by allowing the fields to lie in grass. In Germany, it is considered that for every 100 acres of corn-land, there must, in order to effect a profitable cultivation, be 20 acres of pasture-land, which produce annually, on an average, 500 lbs. of hay. Now, assuming that the ashes of the excrements of the animals fed with this hay amount to 6.82 per cent., then 341 lbs. of the silicate of lime and posphates of magnesia and lime must be yielded by these excrements, and will in a certain measure compensate for the loss which the corn-land had sustained.

The absolute loss in the salts of phosphoric acid, which are not again replaced, is spread over so great an extent of surface, that it scarcely deserves to be taken account of. But the loss of phosphates is again replaced in the pastures by the ashes of the wood used in our houses for fuel.

We could keep our fields in a constant state of fertility by replacing every year as much as we remove from them in the form of produce; but an increase of fertility, and consequent increase of crop, can only be obtained when we add more to them than we take away. It will be found, that of two fields placed under conditions otherwise similar, the one will be most fruitful upon which the plants are enabled to appropriate more easily and in greater abundance those contents of the soil which are essential to their growth and developement.

From the foregoing remarks it will readily be inferred, that for animal excrements, other substances containing their essential constituents may be substituted. In Flanders, the yearly loss of the necessary matters in the soil is completely restored by covering the fields with ashes of wood or bones, which may or may not have been lixiviated, and of which the greatest part consists of the phosphates of lime and magnesia. The great importance of manuring with ashes has been long recognised by agriculturists as the result of experience. So great a value, indeed, is attached to this material in the vicinity of Marburg and in the Wetterau,[*] that it is transported as a manure from the distance of 18 or 24 miles. Its use will be at once perceived, when it is considered that the ashes, after having been washed with water, contain silicate of potash exactly in the same proportion as in straw (10 Si O 3 + K O.,) and that their only other constituents are salts of phosphoric acid.

But ashes obtained from various kinds of trees are of very unequal value for this purpose; those from oak-wood are the least,

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[*] 100 lbs. of flesh contain on an average 15·86 of muscular fibre: 18 parts of nitrogen are contained in 100 parts of the latter.

[†] Dr. C. T. Jackson in his "Geological and Agricultural Survey of Rhode Island," (page 205.) gives the following analysis of horse-dung:—500 grains, dried at a heat a little above that of boiling water, lost 357 grains of water. The dry mass weighing 143 grains was burned, and left 8·5 grains of ashes, of which 4·80 grains were soluble in dilute nitric acid, and 3·20 insoluble. The ashes being analysed, gave

Silica	3·2
Phosphate of lime . . .	0·4
Carbonate of lime . . .	1·5
Phosphate of magnesia and soda .	2·9
	8·0

It consists, then, of the following ingredients:—

Water	357·0
Vegetable fibre and animal matter	135·0
Silica	3·2
Phosphate of lime . .	0·4
Carbonate of lime . . .	1·5
Phosphate of magnesia and soda .	2·9
	500·0

[*] It has been formerly stated (page 41) that all the potash contained in the food of a cow is again discharged in its excrements. The same also takes place with the other inorganic constituents of food, either when they are not adapted for assimilation, or when present in superabundant quantities. The value of manure may thus be artificially increased. We lately saw, for example, some cow-dung, sent by a farmer, who wished to ascertain the cause of its increased value. He had formerly employed this manure for his land, but with so little advantage that he found it more profitable to dry it, and use it as fuel. On inquiry, it was found, that his cows had been fed upon oil-cake. This species of food is particularly rich in phosphates. More of these salts being present than were requisite for the purpose of assimilation, they were removed from the system in the form of excrementitious matter, and in a condition adapted for the uses of plants. The fact that particular kinds of food enrich or impoverish the manure obtained from the cattle fed upon them, has repeatedly been observed.—Ed

[*] The details of the analysis are as follows:—2·356 grammes left 0·320 gramme ashes after incineration; these consisted of the phosphate of lime and magnesia. 0·352 gramme yielded, on combustion with oxide of copper, 0·576 gram. carbonic acid, and 0·218 gram. water. (L. P.)

[*] Two well-known agricultural districts; the first in Hesse-Cassel, the second in Hesse-Darmstadt.

and those from beech the most serviceable. The ashes of oak-wood contain only traces of phosphates, those of beech the fifth part of their weight, and those of the pine and fir from 9 to 15 per cent. The ashes of pines from Norway contain an exceedingly small quantity of phosphates, namely, only 1·8 per cent. of phosphoric acid. (Berthier.)

With every 100 lbs. of the lixiviated ashes of the beech which we spread over a soil, we furnish as much phosphates as 460 lbs. of fresh human excrements could yield. Again, according to the analysis of De Saussure, 100 parts of the ashes of the grain of wheat contain 32 parts of soluble, and 44·5 of insoluble phosphates, in all 76·5 parts. Now the ashes of wheat straw contain 11·5 per cent. of the same salts; hence with every 100 lbs. of the ashes of the beech, we supply a field with phosphoric acid sufficient for the production of 3820 lbs. of straw (its ashes being calculated at 4·3 per cent., De Saussure,) or for 15-18000 lbs. of corn, the ashes of which amount, according to De Saussure, to 1·3 per cent.

Bone manure possesses a still greater importance in this respect. The primary sources from which the bones of animals are derived are, the hay, straw, or other substances which they take as food. Now, if we admit that bones contain 55 per cent. of the phosphates of lime and magnesia (Berzelius,) and that hay contains as much of them as wheat-straw, it will follow that 8 lbs. of bones contain as much phosphate of lime as 1000 lbs. of hay or wheat-straw, and 2 lbs. of it as much as 1000 lbs. of the grain of wheat or oats. These numbers express pretty nearly the quantity of phosphates which a soil yields annually on the growth of hay and corn. Now the manure of an acre of land with 40 lbs. of bone dust is sufficient to supply three crops of wheat, clover, potatoes, turnips, &c., with phosphates. But the form in which they are restored to a soil does not appear to be a matter of indifference. For the more finely the bones are reduced to powder, and the more intimately they are mixed with the soil, the more easily are they assimilated. The most easy and practical mode of effecting their division is to pour over the bones, in a state of fine powder, half of their weight of sulphuric acid diluted with three or four parts of water, and after they have been digested for some time, to add one hundred parts of water, and sprinkle this mixture over the field before the plough. In a few seconds, the free acids unite with the bases contained in the earth, and a neutral salt is formed in a very fine state of division. Experiments instituted on a soil formed from grauwacke, for the purpose of ascertaining the action of manure thus prepared, have distinctly shown that neither corn, nor kitchen-garden plants, suffer injurious effects in consequence, but that on the contrary they thrive with much more vigour.

It has also been found that bones act more speedily and efficaciously after being boiled. This is probably owing to the removal of fatty matter, the presence of which impedes the putrefaction of the gelatin contained in them.

In the manufactories of glue, many hundred tons of a solution of phosphates in muriatic acid are yearly thrown away as being useless. It would be important to examine whether this solution might not be substituted for the bones. The free acid would combine with the alkalies in the soil, especially with the lime, and a soluble salt would thus be produced, which is known to possess a favourable action upon the growth of plants. This salt, muriate of lime (or chloride of calcium,) is one of those compounds which attracts water from the atmosphere with great avidity, and in dry lands might advantageously supply the place of gypsum in decomposing carbonate of ammonia, with the formation of sal-ammoniac and carbonate of lime. A solution of bones in muriatic acid placed on land in autumn or in winter would, therefore, not only restore a necessary constituent of the soil, and attract moisture to it, but would also give it the power to retain all the ammonia which fell upon it dissolved in the rain during the period of six months.*

The ashes of brown coal and peat often contain silicate of potash, so that it is evident that these might completely replace one of the principal constituents of the dung of the cow and horse, and they contain also some phosphates. Indeed they are much esteemed in the Wetterau as manure for meadows and moist land.

It is of much importance to the agriculturist that he should not deceive himself respecting the causes which give the peculiar action to the substances just mentioned. It is known that they possess a very favourable influence on vegetation; and it is likewise certain that the cause of this is their containing a body, which, independently of the influence which it exerts by virtue of its form, porosity, and capability of attracting and retaining moisture, also assists in maintaining the vital processes in plants. If it be treated as an unfathomable mystery, the nature of this aid will never be known.

In medicine, for many centuries, the mode of action of all remedies was supposed to be concealed by the mystic veil of Isis, but now these secrets have been explained in a

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* Immense quantities of bran are used in all print-works, for the purpose of clearing printed goods. After having served this purpose, it is thrown away. But the insoluble part of bran contains much phosphates of magnesia and soda; it would, therefore, be useful to preserve it as a manure. This has been done for some years in a farm with which I am connected, and its value as a manure has been found so great that it is much preferred to cow-dung. In some works this waste bran is heaped up into little hillocks, which might be disposed of as a manure, instead of being an annoyance on account of the space which it occupies.—Ed.

very simple manner. An unpoetical hand has pointed out the cause of the wonderful and apparently inexplicable healing virtues of the springs in Savoy, by which the inhabitants cured their goître; it was shown that they contain small quantities of iodine. In burnt sponges used for the same purpose, the same element was also detected. The extraordinary efficacy of Peruvian bark was found to depend on a small quantity of a crystalline body existing in it, viz. quinine; and the causes of the various effects of opium were detected in as many different ingredients of that drug.

Calico-printers used for a long time the solid excrements of the cow, in order to brighten and fasten colours on cotton goods; this material appeared quite indispensable, and its action was ascribed to a latent principle which it had obtained from the living organism. But since its action was known to depend on the phosphates contained in it, it has been completely replaced by a mixture of salts, in which the principal constituents are the phosphates of soda and lime.*

Now all such actions depend on a definite cause, by ascertaining which we place the actions themselves at our command.

It must be admitted as a principle of agriculture, that those substances which have been removed from a soil must be completely restored to it, and whether this restoration be effected by means of excrements, ashes, or bones, is in a great measure a matter of indifference. A time will come when fields will be manured with a solution of glass, (silicate of potash,) with the ashes of burnt straw, and with salts of phosphoric acid, prepared in chemical manufactories, exactly as at present medicines are given for fever and goître.

There are some plants which require humus, and do not restore it to the soil by their excrements; whilst others can do without it altogether, and add humus to a soil which contains it in small quantity. Hence a rational system of agriculture would employ all the humus at command for the supply of the former, and not expend any of it for the latter; and would in fact make use of them for supplying the others with humus.

We have now considered all that is requisite in a soil, in order to furnish its plants with the materials necessary for the formation of the woody fibre, the grain, the roots, and the stem, and now proceed to the consideration of the most important object of agriculture, viz. the production of nitrogen in a form capable of assimilation—the production, therefore, of substances containing this element. The leaves, which nourish the woody matter, the roots, from which the leaves are formed, and which prepare the substances for entering into the composition of the fruit, and, in short, every part of the organism of a plant, contain azotised matter in very varying proportions, but the seeds and roots are always particularly rich in them.

Let us now examine in what manner the greatest possible production of substances containing nitrogen can be effected. Nature, by means of the atmosphere, furnishes nitrogen to a plant in quantity sufficient for its normal growth. Now its growth must be considered as normal, when it produces a single seed capable of reproducing the same plant in the following year. Such a normal condition would suffice for the existence of plants, and prevent their extinction, but they do not exist for themselves alone; the greater number of animals depend on the vegetable world for food, and by a wise adjustment of nature, plants have the remarkable power of converting, to a certain degree, all the nitrogen offered to them into nutriment for animals.

We may furnish a plant with carbonic acid, and all the materials which it may require; we may supply it with humus in the most abundant quantity; but it will not attain complete developement unless nitrogen is also afforded to it; an herb will be formed, but no grain; even sugar and starch may be produced, but no gluten.

But when we give a plant nitrogen in considerable quantity, we enable it to attract with greater energy from the atmosphere the carbon which is necessary for its nutrition, when that in the soil is not sufficient; we afford to it a means of fixing the carbon of the atmosphere in its organism.

We cannot ascribe much of the power of the excrements of black cattle, sheep, and horses, to the nitrogen which they contain, for its quantity is too minute. But that contained in the fæces of man is proportionably much greater, although by no means constant. In the fæces of the inhabitants of towns, for example, who feed on animal matter, there is much more of this constituent than in those of peasants, or of such people as reside in the country. The fæces of those who live principally on bread and potatoes are similar in composition and properties to those of animals.

All excrements have in this respect a very variable and relative value. Thus those of black cattle and horses are of great use on soils consisting of lime and sand, which contain no silicate of potash and phosphates; whilst their value is much less when applied to soils formed of argillaceous earth, basalt, granite, porphyry, clinkstone, and even mountain-limestone, because all these contain potash in considerable quantity. In such soils human excrements are extremely beneficial, and increase their fertility in a remarkable degree; they are, of course, as advantageous for other soils also; but for the manure of those first mentioned, the excrements of other animals are quite indispensable.

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* This mixture of salts is sold to calico-printers in large quantities under the name of "dung substitute." It would be well worth experiment to try its effects as a manure upon land. Its cost is 3d. or 4d. per pound, and is not, therefore, dearer than nitrate of soda, which is now so extensively used.—Ed.

OF URINE.

We possess only one other natural source of manure which acts by its nitrogen, besides the fæces of animals,—namely, the urine of man and animals.

Urine is employed as manure either in the liquid state, or with the fæces which are impregnated with it. It is the urine contained in them which gives to the solid fæces the property of emitting ammonia,—a property which they themselves possess only in a very slight degree.

When we examine what substances we add to a soil by supplying it with urine, we find that this liquid contains in solution ammoniacal salts, uric acid (a substance containing a large quantity of nitrogen,) and salts of phosphoric acid.

According to Berzelius 1000 parts of human urine contain:—

Urea - - - - - - - -	30·10
Free Lactic acid, Lactate of Ammonia, and animal matter not separable from them	17·14
Uric acid - - - - - - -	1·00
Mucus of the bladder - - - - -	0·32
Sulphate of Potash - - - - -	3·71
Sulphate of Soda - - - - -	3·16
Phosphate of Soda - - - - - -	2·94
Phosphate of Ammonia - - - -	1·65
Chloride of Sodium - - - - -	4·45
Muriate of Ammonia - - - - -	1·50
Phosphates of Magnesia and Lime - -	1·00
Silicious earth - - - - - -	0·03
Water - - - - - - - - -	933·00
	1000 00

If we subtract from the above the urea, lactate of ammonia, free lactic acid, uric acid, the phosphate and muriate of ammonia; 1 per cent. of solid matter remains, consisting of inorganic salts, which must possess the same action when brought on a field, whether they are dissolved in water or in urine. Hence the powerful influence of urine must depend upon its other ingredients, namely, the urea and ammoniacal salts. The urea in human urine exists partly as lactate of urea, and partly in a free state. (Henry.) Now when urine is allowed to putrefy spontaneously, that is, to pass into that state in which it is used as manure, all the urea in combination with lactic acid is converted into lactate of ammonia, and that which was free, into volatile carbonate of ammonia.

In dung-reservoirs well constructed and protected from evaporation, this carbonate of ammonia is retained in the state of solution, and when the putrefied urine is spread over the land, a part of the ammonia will escape with the water which evaporates, but another portion will be absorbed by the soil, if it contains either alumina or iron; but in general only the muriate, phosphate, and lactate of ammonia remain in the ground. It is these alone, therefore, which enable the soil to exercise a direct influence on plants during the progress of their growth, and not a particle of them escapes being absorbed by the roots.

On account of the formation of this carbonate of ammonia the urine becomes alkaline, although it is acid in its natural state. When it is lost by being volatilized in the air, which happens in most cases, the loss suffered is nearly equal to one half of the weight of the urine employed, so that if we fix it, that is, if we deprive it of its volatility, we increase its action two-fold. The existence of carbonate of ammonia in putrefied urine long since suggested the manufacture of sal-ammoniac from this material. When the latter salt possessed a high price, this manufacture was even carried on by the farmer. For this purpose the liquid obtained from dunghills was placed in vessels of iron, and subjected to distillation; the product of this distillation was converted into muriate of ammonia by the common method. (Demachy.) But it is evident that such a thoughtless proceeding must be wholly relinquished, since the nitrogen of 100 lbs. of sal-ammoniac (which contains 26 parts of nitrogen) is equal to the quantity of nitrogen contained in 1200 lbs. of the grain of wheat, 1480 lbs. of that of barley, or 2755 lbs. of hay. (Boussingault.)

The carbonate of ammonia formed by the putrefaction of urine, can be fixed or deprived of its volatility in many ways.

If a field be strewed with gypsum, and then with putrefied urine or the drainings of dunghills, all the carbonate of ammonia will be converted into the sulphate which will remain in the soil.

But there are still simpler means of effecting this purpose;—gypsum, chloride of calcium, sulphuric or muriatic acid, and superphosphate of lime, are all substances of a very low price, and completely neutralise the urine, converting its ammonia into salts which possess no volatility.

If a basin, filled with concentrated muriatic acid, is placed in a common necessary, so that its surface is in free communication with the vapours which rise from below, it becomes filled after a few days with crystals of muriate of ammonia. The ammonia, the presence of which the organs of smell amply testify, combines with the muriatic acid and loses entirely its volatility, and thick clouds or fumes of the salt newly formed hang over the basin. In stables the same may be seen. The ammonia that escapes in this manner is not only entirely lost, as far as our vegetation is concerned, but it works also a slow, though not less certain destruction of the walls of the building. For when in contact with the lime of the mortar, it is converted into nitric acid, which gradually dissolves the lime. The injury thus done to a building by the formation of the soluble nitrates, has received (in Germany) a special name—salpeterfrass.

The ammonia emitted from stables and necessaries is always in combination with carbonic acid. Carbonate of ammonia and sulphate of lime (gypsum) cannot be brought together at common temperatures, without mutual decomposition. The ammonia enters into combination with the sulphuric acid, and the carbonic acid with the lime, forming compounds which are not volatile, and consequently destitute of all smell. Now, if we strew the floors of our stables, from time to time, with common gypsum, they will lose all their offensive smell, and none of the ammonia which forms can be lost, but will be retained in a condition serviceable as manure.

With the exception of urea, uric acid contains more nitrogen than any other substance generated by the living organism; it is soluble in water, and can be thus absorbed by the roots of plants, and its nitrogen assimilated in the form of ammonia, and of the oxalate, hydrocyanate, or carbonate of ammonia.

It would be extremely interesting to study the transformations which uric acid suffers in a living plant. For the purpose of experiment, the plant should be made to grow in charcoal powder previously heated to redness, and then mixed with pure uric acid. The examination of the juice of the plant, or of the component parts of the seed or fruit, would be a means of easily detecting the differences.

NIGHT-SOIL.

In respect to the quantity of nitrogen contained in excrements, 100 parts of the urine of a healthy man are equal to 1300 parts of the fresh dung of a horse, according to the analyses of Macaire and Marcet, and to 600 parts of those of a cow. Hence it is evident that it would be of much importance to agriculture if none of the human urine were lost. The powerful effects of urine as a manure are well known in Flanders,* but they are considered invaluable by the Chinese, who are the oldest agricultural people we know. Indeed so much value is attached to the influence of human excrements by these people, that laws of the state forbid that any of them should be thrown away, and reservoirs are placed in every house, in which they are collected with the greatest care. No other kind of manure is used for their corn-fields.†

China is the birth-place of the experimental art; the incessant striving after experiments has conducted the Chinese a thousand years since to discoveries, which have been the envy and admiration of Europeans for centuries, especially in regard to dying and painting, and to the manufactures of porcelain, silk, and colours for painters. These we were long unable to imitate, and yet they were discovered by them without the assistance of scientific principles; for in the books of the Chinese we find recipes and directions for use, but never explanations of processes.

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* See the article "On the Agriculture of the Netherlands," *Journ. Royal Agri. Soc.*, vol. ii. part 1, page 43, for much interesting information on this subject.

† Davis, in his *History of China*, states that every substance convertible into manure is diligently husbanded. "The cakes that remain after the expression of their vegetable oils, horns and hoofs reduced to powder, together with soot and ashes, and the contents of common sewers, are much used. The plaster of old kitchens, which in China have no chimneys but an opening at the top, is much valued; so that they will sometimes put a new plaster on a kitchen for the sake of the old." The ammonia contained in the fuel forms nitrate of lime with the lime in the mortar. "All sorts of hair are used as a manure, and barbers' shavings are carefully appropriated to that purpose. The annual produce must be considerable in a country where some hundred millions of heads are kept constantly shaved. Dung of all animals, but more especially night-soil, is esteemed above all others. Being sometimes formed into cakes, it is dried in the sun, and in this state becomes an object of sale to farmers, who dilute it previous to use. They construct large cisterns or pits, lined with lime plaster, as well as earthen tubs. sunk into the ground, with straw over them to prevent evaporation, in which all kinds of vegetables and animal refuse are collected. These being diluted with a sufficient quantity of liquid, are left to undergo the putrefactive fermentation, and then applied to the land. In the case of every thing except rice, the Chinese seem to manure the plant itself rather than the soil, supplying it copiously with their liquid preparation."

"The Chinese husbandman," observes Sir G. Staunton, (*Embassy*, vol. ii.,) "always steeps the seeds he intends to sow in liquid manure, until they swell, and germination begins to appear, which experience has taught him will have the effect of hastening the growth of plants, as well as of defending them against the insects hidden in the ground in which the seeds are sown. To the roots of plants and fruit-trees, the Chinese farmer applies liquid manure likewise."

Lastly, we extract the following from a communication to Professor Webster, of Harvard College, United States:—"Human urine is, if possible, more husbanded by the Chinese than night-soil for manure; every farm, or patch of land for cultivation, has a tank, where all substances convertible into manure are carefully deposited, the whole made liquid by adding urine in the proportion required, and invariably applied in that state." This is exactly the process followed in the Netherlands. See *Outlines of Flemish Husbandry*, page 22.

"The business of collecting urine and night-soil employs an immense number of persons, who deposit tubs in every house in the cities for the reception of the urine of the inmates, which vessels are removed daily, with as much care as our farmers remove their honey from the hives."

When we consider the immense value of night-soil as a manure, it is quite astounding that so little attention is paid to preserve it. The quantity is immense which is carried down by the drains in London to the River Thames, serving no other purpose than to pollute its waters. It has been shown, by a very simple calculation, that the value of the manure thus lost amounts annually to several *millions of pounds sterling*. A substance, which by its putrefaction generates miasmata, may, by artificial means, be rendered totally inoffensive, inodorous, and transportable, and yet prejudice prevents these means being resorted to. —Ed.

Half a century sufficed to Europeans not only to equal but to surpass the Chinese in the arts and manufactures, and this was owing merely to the application of correct principles deduced from the study of chemistry. But how infinitely inferior is the agriculture of Europe to that of China! The Chinese are the most admirable gardeners and trainers of plants, for each of which they understand how to prepare and apply the best-adapted manure. The agriculture of their country is the most perfect in the world; and there, where the climate in the most fertile districts differs little from the European, very little value is attached to the excrements of animals. With us, thick books are written, but no experiments instituted; the quantity of manure consumed by this and that plant is expressed in hundredth parts, and yet we know not what manure is!

If we admit that the liquid and solid excrements of man amount on an average to 1½ lb. daily, ($\frac{5}{4}$ lb. of urine and ¼ lb. fæces,) and that both taken together contain 3 per cent. of nitrogen, then in one year they will amount to 547 lbs., which contain 16·41 lbs. of nitrogen, a quantity sufficient to yield the nitrogen of 800 lbs. of wheat, rye, oats, or of 900 lbs. of barley. (Boussingault.)

This is much more than is necessary to add to an acre of land in order to obtain, with the assistance of the nitrogen absorbed from the atmosphere, the richest possible crop every year. Every town and farm might thus supply itself with the manure, which, besides containing the most nitrogen, contains also the most phosphates; and if rotation of the crops were adopted, they would be most abundant. By using, at the same time, bones and the lixiviated ashes of wood, the excrements of animals might be completely dispensed with.

When human excrements are treated in a proper manner, so as to remove the moisture which they contain without permitting the escape of ammonia, they may be put into such a form as will allow them to be transported even to great distances.

This is already attempted in many towns, and the preparation of night-soil for transportation constitutes not an unimportant branch of industry. But the manner in which this is done is the most injudicious which could be conceived. In Paris, for example, the excrements are preserved in the houses in open casks, from which they are collected and placed in deep pits at Montfaucon, but are not sold until they have attained a certain degree of dryness by evaporation in the air. But whilst lying in the receptacles appropriated for them in the houses, the greatest part of their urea is converted into carbonate of ammonia; lactate and phosphate of ammonia are also formed, and the vegetable matters contained in them putrefy; all their sulphates are decomposed, whilst their sulphur forms sulphuretted hydrogen and hydro-sulphate of ammonia. The mass, when dried by exposure to the air, has lost more than half of the nitrogen which the excrements originally contained; for the ammonia escapes into the atmosphere along with the water which evaporates; and the residue now consists principally of phosphate of lime, with phosphate and lactate of ammonia, and small quantities of urate of magnesia and fatty matter. Nevertheless it is still a very powerful manure, but its value as such would be twice or four times as great, if the excrements before being dried were neutralised with a cheap mineral acid.

In other manufactories of manure the night-soil, whilst still soft, is mixed with the ashes of wood, or with earth, both of which substances contain a large quantity of caustic lime, by means of which a complete expulsion of all its ammonia is effected, and it is completely deprived of smell. But such a residue applied as manure can act only by the phosphates which it still contains, for all the ammoniacal salts have been decomposed and their ammonia expelled.

The preparation of night-soil is now carried on in London to a considerable extent. Owing to the variable nature of the climate, artificial means are employed in its desiccation. The night-soil, after being subjected to one or other of the modes of treatment described below, is placed upon iron plates heated by means of furnaces.

As soon as the night-soil is collected, it is placed in large broad trenches, until a sufficient quantity is accumulated for the purposes of the manufacturer. But here it undergoes the same process of putrefaction to which allusion has been made, and acquires a peculiarly offensive smell from the evolution of sulphuretted hydrogen and other gases, which are observed to escape. Unless some means be employed, at this stage of the process, to retain the ammonia, it escapes into the atmosphere in the form of a carbonate. Various methods have been proposed to effect this purpose. Some manufacturers mix the night-soil with chloride of lime, and evaporate off the water by the aid of heat. This possesses the advantage of depriving the excrements of smell, and at the same time partially fixes the ammonia which would otherwise escape. Chloride of lime always contains a considerable excess of lime; hence part of the ammonia contained in the night-soil is expelled by means of it.

More simple and economical methods might be employed. A patent, which has been taken out for the preparation of this useful manure, states in its specification, that the night-soil is to be mixed with calcined mud and finely-divided charcoal. By this means, the smell is completely and instantaneously removed, and the ammonia retained by virtue of the affinity which alumina and charcoal exert for that compound. This plan is both simple and efficacious, but the ammonia is apt to be expelled by the application of the heat employed in drying the manure. The addition of a cheap mineral acid to the night-soil, before admixture with these ingredients, would materially improve both of the above processes.

It would no doubt be highly advantageous in the preparation of manures, to prepare them so that they contained all the ingredients necessary for the supply of the plants to which they are applied. But these will of course vary according to the nature of the soils and plants for which they are intended. Thus bones, soap-boilers' waste, nitrate of soda, and ashes of wood, will often be found to form advantageous additions. Sulphate of magnesia (Epsom salts) would, in most cases, form an invaluable ingredient in prepared night-soil. (See Supplementary Chapter on Soils.) The products of the decomposition proceeding from the action of this salt upon night-soil are, sulphate of ammonia, phosphate of magnesia, and the double phosphate of magnesia and ammonia. Now all these salts exert a very favourable influence upon vegetation, and the phosphate of magnesia is, in many cases, perfectly indispensable to the growth and developement of certain plants. This suggestion is well worthy of the attention of the farmer.

Perhaps the best and most practical method of fixing the ammoniacal salts of urine and night-soil, is to mix them with the ashes of peat or coal. When the latter are employed, care must be taken to select such as are of a porous, earthy consistence. The ashes both of peat and coal contain in general magnesia; hence their value as an ingredient of prepared night-soil. When magnesia is not present, it will be necessary to add some magnesian limestone or Epsom salts. The night-soil should be mixed thoroughly with the ashes, and exposed to the air to dry. The disagreeable smell is thus quickly removed, and a pulverulent manure obtained, which can be applied to the fields with facility.

Animal charcoal, which has served for the discoloration of sugar, possesses the property of removing the offensive smell of night-soil, and is of itself an admirable manure. In cases where it can be procured with facility, it will be found to add to the efficacy of the latter.

GUANO.

The sterile soils of the South American coast are manured with a substance called guano, consisting of urate of ammonia and other ammoniacal salts, by the use of which a luxuriant vegetation and the richest crops are obtained. Guano has lately been imported in considerable quantity into Liverpool and several other English ports, and is now experimentally employed as a manure by English agriculturists. A consideration of its composition and mode of action cannot, therefore, fail to be acceptable.

Much speculation has arisen as to the true origin of guano,* but the most certain proof is now afforded, that it has been produced by the accumulation of the excrements of innumerable sea-fowl which inhabit the islands upon which it is found. Meyen, the latest writer upon this subject, completely coincides with this opinion; for he says†—"Their number is Legion; they completely cloud the sun, when they rise from their resting-place in the morning in flocks of miles in length." Yet, notwithstanding their great number, thousands of years must have elapsed, before the excrements could have accumulated to such a thickness as they possess at present. Guano has been used by the Peruvians as a manure since the twelfth century; and its value was considered so inestimable, that the government of the Incas issued a decree, by which capital punishment was inflicted upon any person found destroying the fowl on the Guano islands. Overseers were also appointed over each province, for the purpose of insuring them further protection. Under this state of things, the accumulation of the excrements may have well taken place. All these regulations are, however, now abandoned.‡ Rivero states that the annual consumption of guano for the purposes of agriculture amounts to 40,000 *fanegas*. The increase of crops obtained by the use of guano is very remarkable. According to the same authority, the crop of potatoes is increased 45 times by means of it, and that of maize 35 times. The manner of applying the manure is singular. Thus in Arica, where so much pepper (*Capsicum baccatum*) is cultivated, each plant is manured three times: first upon the appearance of the roots, second upon that of the leaves, and lastly upon the formation of the fruit. (Humboldt.) From this it will be observed, that the Peruvians follow the plan of the Chinese, in manuring the plant rather than the soil. The composition of guano points out how admirably it is fitted for a manure; for not only does it contain ammoniacal salts in abundance, but also those inorganic constituents which are indispensable for the developement of plants.

The most recent analysis is that of Völckel, who found it to consist of

Urate of Ammonia	9.0
Oxalate of Ammonia	10.6
Oxalate of Lime	7.0
Phosphate of Ammonia	6.0
Phosphate of Magnesia and Ammonia .	2.6
Sulphate of Potash	5.5
Sulphate of Soda	3.8
Sal-ammoniac . . , . .	4.2
Phosphate of Lime	14.3
Clay and Sand . . : . .	4.7

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[*] Much of the information regarding Guano here given is extracted from a paper in *Liebig's Annalen*, xxxvii. 3, 291.

[†] *Reise um die Erde*, B. i. S. 434.

[‡] Garcilaso, *Historia de los Yncas*, vol. i p. 134.

	—67.7
Organic substances not estimated, containing 12 per cent. of matter insoluble in water. Soluable Salts of Iron in small quantity. Water.	32.3
	100.0

It will be observed from the above analysis, that urea does not enter into the composition of guano. The uric acid of the excrements must have been decomposed into oxalic acid and ammonia. The soluble substances contained in guano amount to half its weight. It is singular that we do not find nitrates amongst the ingredients which compose it. Guano possesses a urinous smell, precisely similar to that perceived on the evaporation of urine. The experiments upon the efficacy of this manure in England have not yet been sufficiently multiplied to enable us to judge whether or not its virtues have been overrated.

The corn-fields in China receive no other manure than human excrements. But we cover our fields every year with the seeds of weeds, which from their nature and form pass undigested along with the excrements through animals, without being deprived of their power of germination, and yet it is considered surprising that where they have once flourished, they cannot again be expelled by all our endeavours: we think it very astonishing, while we really sow them ourselves every year. A famous botanist, attached to the Dutch embassy to China, could scarcely find a single plant on the corn-fields of the Chinese, except the corn itself.*

The urine of horses contains less nitrogen and phosphates than that of man. According to Fourcroy and Vauquelin it contains only five per cent. of solid matter, and in that quantity only 0.7 of urea; whilst 100 parts of the urine of man contain more than four times as much.

The urine of a cow is particularly rich in salts of potash; but according to Rouelle and Brande, it is almost destitute of salts of soda. The urine of swine contains a large quantity of the phosphate of magnesia and ammonia; and hence it is that concretions of this salt are so frequently found in the urinary bladders of these animals.

It is evident that if we place the solid or liquid excrements of man or the liquid excrements of animals on our land, in equal proportion to the quantity of nitrogen removed from it in the form of plants, the sum of this element in the soil must increase every year; for to the quantity which we thus supply, another portion is added from the atmosphere. The nitrogen which we export as corn and cattle, and which is thus absorbed by large towns, serves only to benefit other farms, if we do not replace it. A farm which possesses no pastures, and not fields sufficient for the cultivation of fodder, requires manure containing nitrogen to be imported from elsewhere, if it is desired to produce a full crop. In large farms, the annual expenditure of nitrogen is completely replaced by means of the pastures.

The only absolute loss of nitrogen, therefore, is limited to the quantity which man carries with him to his grave; but this at the utmost cannot amount to more than 3 lbs. for every individual, and is being collected during his whole life. Nor is this quantity lost to plants, for it escapes into the atmosphere as ammonia during the putrefaction and decay of the body.

A high degree of culture requires an increased supply of manure. With the abundance of the manure, the produce in corn and cattle will augment, but must diminish with its deficiency.

From the preceding remarks it must be evident, that the greatest value should be attached to the liquid excrements of man and animals, when a manure is desired which shall supply nitrogen to the soil. The greatest part of a superabundant crop, or, in other words, the increase of growth which is in our power, can be obtained exclusively by their means.

When it is considered that with every pound of ammonia which evaporates a loss of 60 lbs. of corn is sustained, and that with every pound of urine a pound of wheat might be produced, the indifference with which these liquid excrements are regarded is quite incomprehensible. In most places only the solid excrements impregnated with the liquid are used, and the dunghills containing them are protected neither from evaporation nor from rain. The solid excrements contain the insoluble, the liquid all the soluble phosphates, and the latter contain likewise all the potash which existed as organic salts in the plants consumed by the animals.

Fresh bones, wool, hair, hoofs, and horn, are manures containing nitrogen as well as phosphates, and are consequently fit to aid the process of vegetable life. All animal matter is fitted for the same purpose. Butchers' offal, such as the blood and intestines of animals, form a most powerful manure. It is in general necessary to dilute such manure by admixture with other kinds less powerful in their action.

One hundred parts of dry bones contain from 32 to 33 per cent. of dry gelatine; now supposing this to contain the same quantity of nitrogen as animal glue, viz., 5.28 per cent., then 100 parts of bones must be considered as equivalent to 250 parts of human urine.

Bones may be preserved unchanged for thousands of years, in dry or even in moist soils, provided the excess of rain is prevented; as is exemplified by the bones of antediluvian animals found in loam or gypsum, the interior parts being protected by the exterior from the action of water. But they become warm when reduced to a fine powder, and moistened bones generate heat and enter into putrefaction; the gelatine which they contain is decomposed, and its nitrogen converted into carbonate of ammonia and other ammoniacal salts, which are retained in a great measure by the powder itself. (Bones burnt till quite white, and recently heated to redness, absorb 7.5 times their volume of pure ammoniacal gas.)

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* Ingenhouss on the Nutrition of Plants, page 129 (German edition.)

ARTIFICIAL MANURES.

We have now examined the action of the animal or natural manures upon plants; but it is evident that if artificial manures contain the same constituents, they will exercise a similar action upon the plants to which they are applied. We shall only notice here one or two of those principally employed.

Since it has been ascertained that animal manures act (as far as the formation of *organic* matter is concerned) only by the ammonia which they contain, attention has been devoted by chemists to discover a more economical means of presenting this ammonia to plants. The water which distils from the retorts in the preparation of coal gas is strongly charged with this alkali, but is at the same time mixed with tar and other empyreumatic impurities. It has been customary to allow the tarry matter to subside, and decant off the clear, supernatant liquor. This liquor, being diluted to such a degree as to be tasteless, is applied as a manure to the field.

Now, the ammoniacal liquor of the gas-works contains the ammonia in the form of carbonate and hydro-sulphate of ammonia (sulphuret of ammonium). The latter compound is a deadly poison to vegetables, nor can we conceive that by dilution its properties can be changed. The carbonate of ammonia is volatile, and escapes into the atmosphere. To obviate this latter inconvenience and render it more transportable, it has been proposed to convert the carbonate into the sulphate, by means of gypsum.* But this does not remove the hydro-sulphate. A more simple and efficacious method is to add a solution of sulphate of iron (the green vitriol of the shops) to the liquor, until no further precipitation ensues. Sulphuret and carbonate of iron are thus formed, and the whole of the ammonia enters into combination with the sulphuric acid, and forms sulphate of ammonia. Care must be taken to avoid too great an excess of sulphate of iron; and the liquor thus prepared should be freely exposed to the air to promote the oxidation.

The liquor still, however, contains empyreumatic matters, which are injurious to plants. These may be removed by evaporating the liquor to dryness, and heating the residue to incipient redness. By this means they are rendered insoluble, and the sulphate of ammonia is not affected, unless the heat has been carried too far. The liquor properly diluted has been found very advantageous, even without the removal of the empyreumatic matter.

Nitrate of soda has lately engaged much attention, and is supposed to exert its favourable action upon vegetation by yielding nitrogen to those of their constituents which contain it. The experiments which have hitherto been instituted with this manure do not warrant us in concluding with positive certainty that it is the nitrogen alone to which it owes its efficacy, but they certainly render this a plausible explanation of its virtues. Thus Mr. Pusey, the late able president of the Royal Agricultural Society, has shown, that the same effects are produced by putrefied urine, soot, gas-liquor, and nitrate of soda.* Now the three former act by virtue of the ammonia which enters into their composition. The usual effects produced by these and nitrate of soda are to increase the intensity of the green colouring matter, to augment the quantity of straw, but to produce a light grain. Mr. Hyett† has communicated the results of an analysis of two samples of wheat grown under similar circumstances, one of which had been treated with nitre, the other not. The former contained 23·25 per cent. of gluten, and 1·375 of albumen; the latter only 19 per cent. of gluten, and 0·62 of albumen. Here the azotised matters appear to have considerably increased in quantity. There is nothing opposed to the supposition that nitric acid may be decomposed by plants, and its nitrogen assimilated. We find that vegetables possess the power of decomposing carbonic acid, and of appropriating its carbon for their own use. Now this acid is infinitely more difficult to decompose than nitric acid. But there are other circumstances which oppose the adoption of the view that nitrate of soda acts by virtue of the nitrogen which enters into its composition. Were this the case, the action should be more uniform than it has hitherto been found to be. On some soils the salt does not possess the smallest influence; whilst on others it affords great benefit. We can only furnish an explanation of this seeming caprice by a reference to the chemical composition of the soil upon which it is applied. If the advantages attending the application of nitrate of soda are due to the alkaline base which it contains, then it is evident that this manure can be of small value on soils containing a quantity of alkalies sufficient for the purposes of the plants grown upon them; whilst, on the other hand, such as are deficient in these must experience benefit through its means.‡ In certain cases in which nitrate of soda has failed, nitrate of potash (common saltpetre) has been very successful. Analyses of wheat grown with nitrate of soda and nitrate of potash would be of interest, in order to determine whether a mutual substitution of their respective bases is effected. It is to be hoped that future experiments will throw more light upon the action of this interesting manure, for theory cannot be satisfied with those already existing. It has been usual to employ a less quantity by weight of nitrate of potash than of nitrate of soda. This procedure seems rather empirical, for unless sanctioned by experience, it would *à priori* appear to be better to add the greatest quantity of that salt which possesses the highest equivalent. Now the equivalent of nitrate of potash is considerably higher than that of nitrate of soda.

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* Three Lectures on Agriculture, by Dr. Daubeny, page 87

* Journal of the Royal Agricultural Society, vol. ii., p. 123.

† Journal of the Royal Agricultural Society, vol. ii., p. 143.

‡ General Sir Howard Elphinstone informs me that he found carbonate of soda (soda ash) an ex

Charcoal in a state of powder must be considered as a very powerful means of promoting the growth of plants on heavy soils, and particularly on such as consist of argillaceous earth.*

Ingenhouss proposed dilute sulphuric acid as a means of increasing the fertility of a soil. Now, when this acid is sprinkled on calcareous soils, gypsum (sulphate of lime) is immediately formed, which of course prevents the necessity of manuring the soils with this material. 100 parts of concentrated sulphuric acid diluted with from 800 to 1000 parts of water, are equivalent to 176 parts of gypsum.

SUPPLEMENTARY CHAPTER.

ON THE CHEMICAL CONSTITUENTS OF SOILS.

THE fertility of a soil is much influenced by its physical properties, such as its porosity, colour, attraction for moisture, or state of disintegration. But independently of these conditions, the fertility depends upon the chemical constituents of which the soil is composed.

We have already shown, at considerable length, that those alkalies, earths, and phosphates, which constitute the ashes of plants, are perfectly indispensable for their developement; and that plants cannot flourish upon soils from which these compounds are absent. The necessity of alkalies for the vital processes of plants will be obvious, when we consider that almost all the different families of plants are distinguished by containing certain acids, differing very much in composition; and further, that these acids do not exist in the juice in an isolated state, but generally in combination with certain alkaline or earthy bases. The juice of the vine contains tartaric acid, that of the sorrel oxalic acid. It is quite obvious that a peculiar action must be in operation in the organism of the vine and sorrel, by means of which the generation of tartaric and oxalic acid is effected; and also that the same action must exist in all plants of the same genus. A similar cause forces corn-plants to extract silicic acid from the soil. The number of acids found in different plants is very numerous, but the most common are those which we have already mentioned; to which may be added acetic, malic, citric, aconitic, maleic, kinovic acids, &c.

When we observe that the proper acids of each family of plants are never absent from it, we must admit that the plants belonging to that family could not attain perfection, if the generation of their peculiar acids were prevented. Hence, if the production of tartaric acid in the vine were rendered impossible, it could not produce grapes, or in other words, would not fructify. Now the generation of organic acids is prevented in the vine, and, indeed, in all plants which yield nourishment to men and animals, when alkalies are absent from the soil in which they grow. The organic acids in plants are very rarely found in a free state; in general, they are in combination with potash, soda, lime, or magnesia. Thus, silicic acid is found as silicate of potash, acetic acid as acetate of potash or soda, oxalic acid as oxalate of potash, soda, or lime, tartaric acid as bitartrate of potash, &c. The potash, soda, lime, and magnesia in these plants are, therefore, as indispensable for their existence as the carbon from which their organic acids are produced.

In order not to form an erroneous conclusion regarding the processes of vegetable nutrition, it must be admitted that plants require certain salts for the sustenance of their vital functions, the acids of which salts exist either in the soil (such as silicic or phosphoric acids) or are generated from nutriment derived from the atmosphere. Hence, if these salts are not contained in the soil, or if the bases necessary for their production be absent, they cannot be formed, or in other words, plants cannot grow in such a soil. The juice, fruit, and leaves of a plant cannot attain maturity, if the constituents necessary for their formation are wanting, and salts must be viewed as such. These salts do not, however, occur simultaneously in all plants. Thus, in saline plants, soda is the only alkali found; in corn plants, lime and potash form constituents. Several contain both soda and potash, some both potash and lime; whilst others contain potash and magnesia. The acids vary in a similar manner. Thus one plant may contain phosphate of lime, a second, phosphate of magnesia, a third, an alkali combined with silicic acid, and a fourth, an alkali in combination with a vegetable acid. The respective quantities of the salts required by plants are very unequal. The aptitude of a soil to produce one, but not another kind of plant, is due to the presence of a base which the former requires, and the absence of that, indispensable for the developement of the latter. Upon the correct knowledge of the bases and salts requisite for the sustenance of each plant, and of the composition of the soil upon which it grows, depends the whole system of a rational theory of agriculture; and that knowledge alone can explain the process of fallow, or furnish us with the most advantageous methods of affording plants their proper nourishment.

Give—so says the rational theory—to one plant such substances as are necessary for its developement, but spare those, which are not requisite, for the production of other plants that require them.

It is the same with regard to these bases as it is with the water which is necessary for the roots of various plants. Thus, whilst one plant flourishes luxuriantly in an arid soil, a second requires much moisture, a third finds necessary this moisture at the commencement of its developement, and a fourth (such as potatoes) after the appearance of the blossom. It would be very erroneous to present the same quantity of water to all plants indiscriminately. Yet this obvious principle is lost sight of in the manuring of plants. An empirical system of agriculture has administered the same kind of manures to all plants; or when a selection has been made, it was not based upon a knowledge of their peculiar characters or composition.

The cost of labour in England has given rise to the production of much ingenuity in the invention of machines, which have produced improvements in the mode of application of manures. In order to use these with advantage, pulverulent manures are employed, instead of the common stable manure, which is generally mixed with much straw.

The necessity for such forms of manure naturally suggested the employment of bone dust, dried dung, lime, ashes, &c. Now, although by these means the necessary phosphates are furnished to a soil, and solid animal excrements rendered unnecessary, they have led to the neglect of the liquid excrements, that is, of the urine of men and animals, which is thus completely lost to agriculture. For although the meadows receive, during autumn and winter, when cattle are fed upon them, the solid and liquid excrements of these animals, yet the urine of man, into which all the nitrogenous constituents of animals are finally deposited, is completely lost to the fields. This most important of all manures, so properly estimated in Flanders, Germany, and China, is altogether lost to the English agriculturist. In large towns it is either allowed to run into the rivers, or sink into the ground in such a manner as to be of no benefit to the vegetable kingdom.

The most important growth in England is that of wheat; then of barley, oats, beans, and turnips. Potatoes are only cultivated to a great extent in certain localities; rye, beet-root, and rape-seed, not very generally. Lucerne is only known in a few districts, whilst red clover is found universally. Now, the selection of inorganic manures for these plants may be fixed upon by an examination of the composition of their ashes. Thus wheat must be cultivated in a soil rich in silicate of potash. If this soil is formed from feldspar, mica, basalt, clinkstone, or indeed of any minerals which disintegrate with facility, crops of wheat and barley may be grown upon it for many centuries in succession. But, in order to support an uninterrupted succession, the annual disintegration must be sufficiently great to render soluble a quantity of silicate of potash sufficient for the supply of a full crop of wheat or barley. If this is not the case, the soil must either be allowed to lie fallow from time to time, or plants may be cultivated upon it which contain little silicate of potash, or the roots of which are enabled to penetrate deeper into the soil than corn plants in search of this salt. During this interval of repose, the materials of the soil disintegrate, and potash in a soluble state is liberated on the layers exposed to the action of the atmosphere. When this has taken place, rich crops of wheat may be again expected.

The alkaline phosphates, as well as the phosphates of magnesia and lime, are necessary for the production of all corn-plants. Now, bones contain the latter, but none of the former salts. These must, therefore, be furnished by means of night-soil, or of urine, a manure which is particularly rich in them.* Wood ashes have been found very useful for wheat in calcareous soils; for these ashes contain both phosphate of lime and silicate of potash. In like manner stable manure and night-soil render clayey soils fertile, by furnishing the magnesia in which they are deficient. The ashes of all kinds of herbs and decayed straw are capable of replacing wood ashes.

A compost manure, which is adapted to furnish all the inorganic matters to wheat, oats, and barley, may be made, by mixing equal parts of bone dust and a solution of silicate of potash (known as *soluble glass* in commerce,) allowing this mixture to dry in the air, and then adding 10 or 12 parts of gypsum, with 16 parts of common salt. Such a compost would render unnecessary

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cellent manure for his land. The crops obtained by means of it presented the same general characters as those manured with nitrate of potash, and exhibited a greater intensity of colour. If this is found uniformly to be the case, it will very much strengthen the supposition that the action of nitrate of soda is due to its alkaline constituent.—ED.

* For much valuable information on the subject of manures, see "Agricultural Chemistry," vol. viii. of Sir H. Davy's collected Works.

* It has been already stated that bran contains phosphate of soda and phosphate of magnesia, so that it is useful as a manure where phosphates are desired.—ED.

the animal manures, which act by their inorganic ingredients. According to Berthier, 100 parts of the ashes of wheat straw contain—

Of matter soluble in water - -	9·0
Of matter insoluble in water -	81·0

Now 100 parts of the soluble matter contain—

Carbonic acid - - -	a trace
Sulphuric acid - - -	2·0
Muriatic acid - - - -	13·0
Silica - - - -	35·0
Potash and Soda - - -	50.0
	100·0

100 parts of the insoluble matter contain—

Carbonic acid - - -	0
Phosphoric acid - - -	1·2
Silica - - - -	75.0
Lime - - - - -	5·8
Oxide of Iron and Charcoal -	10·0
Potash - - - -	8·0
	100.0

The silicate of potash employed in the preparation of the compost described above must not deliquesce on exposure to the air, but must give a gelatinous consistence to the water in which it is dissolved, and dry to a white powder by exposure. It is only attractive of moisture when an excess of potash is present, which is apt to exert an injurious influence upon the tender roots of plants. In those cases where silicate of potash cannot be procured, a sufficiency of wood ashes will supply its place.[*]

All culinary vegetables, but particularly the cruciferæ, such as mustard, (*sinapis alba* and *nigra*,) contain sulphur in notable quantity. The same is the case with turnips, the different varieties of rape, cabbage, celery, and red clover. These plants thrive best in soils containing sulphates; hence if these salts do not form natural constituents of the soil, they must be introduced as manure. Sulphate of ammonia is the best salt for this purpose. It is most easily procured by the addition of gypsum or sulphate of iron[†] (green vitriol) to putrefied urine.

Horn, wool, and hoofs of cattle, contain sulphur as a constituent, so that they will be found a valuable manure when administered with soluble phosphates, (with urine, for example.)

Phosphate of magnesia and ammonia forms the principal inorganic constituent of the potato; salts of potash also exist in it, but in very limited quantity. Now the soil is rendered unfitted for its cultivation, even though the herb be returned to it after the removal of the crop, unless some means are adopted to replace the phosphate of magnesia removed in the bulbous roots. This is best effected by mixtures of night-soil with bran, magnesian limestone, or the ashes of certain kinds of coal. I applied to a field of potatoes manure, consisting of night-soil and sulphate of magnesia, (Epsom salts,) and obtained a remarkably large crop. The manure was prepared by adding a quantity of sulphate of magnesia to a mixture of urine and fæces, and mixing the whole with the ashes of coal or vegetable mould, till it acquired the consistence of a thick paste, which was thus dried by exposure to the sun.

It has been formerly mentioned, that the secondary and tertiary limestones contain potash: marl, and the calcareous minerals used for the preparation of hydraulic mortar, may be particularly specified. These have been found to form excellent manures for heavy clayey soils, particularly for such as disintegrate with difficulty. They are most efficacious when burnt, but can only be applied in this state after harvest, and ought to be ploughed into the soil as quickly as possible. By the action of lime upon clay, the potash contained in the latter is rendered soluble. This may easily be shown by mixing one part of marl with half its weight of burned lime, adding water, and setting aside the mixture to repose for some time. Even after a space of 24 hours, an appreciable quantity of potash may be detected in the water.[*]

A most striking proof of the influence of potash upon vegetation has been furnished by the investigations of the "*administration*" of tobacco in Paris. For many years accurate analyses of the ashes of various sorts of tobacco have been executed, by the orders of the "administration;" and it has been found, as the result of these, that the value of the tobacco stands in a certain relation to the quantity of potash contained in the ashes. By this means a mode was furnished of distinguishing the different soils upon which the tobacco under examination had been cultivated, as well as the peculiar class to which it belonged. Another striking fact was also disclosed through these analyses. Certain celebrated kinds of American tobacco were found gradually to yield a smaller quantity of ashes, and their value diminished in the same proportion. For this information I am indebted to M. Pelouze, professor of the Polytechnic School in Paris.

There are certain plants which contain either no potash, or mere traces of it. Such are the poppy, (*papaver somniferum*,) which generates in its organism a vegetable alkaloid, Indian corn, (*zea mays*,) and *helianthus tuberosus*. For plants such as these the potash in the soil is of no use, and farmers are well aware that they can be cultivated without rotation on the same soil, particularly when the herbs and straw, or their ashes, are returned to the soil after the reaping of the crop.

One cause of the favourable action of the nitrates of soda and potash must doubtless be, that through their agency the alkalies which are deficient in a soil are furnished to it. Thus it has been found that in soils deficient in potash, the nitrates of soda or potash have been very advantageous; whilst those, on the other hand, which contain a sufficiency of alkalies, have experienced no beneficial effects through their means. In the application of manures to soils we should be guided by the general composition of the ashes of plants, whilst the manure applied to a particular plant ought to be selected with reference to the substances which it demands for its nourishment. In general, a manure should contain a large quantity of alkaline salts, a considerable proportion of phosphate of magnesia, and a smaller proportion of phosphate of lime; azotised manure and ammoniacal salts cannot be too frequently employed.

In the following part of this chapter I shall describe a number of analyses of soils executed by Sprengel, together with observations on their sterility and fertility, as stated by that distinguished agriculturist. It is unnecessary to describe the *modus operandi* used in the analyses of these soils, for this kind of research will never be made by farmers, who must apply to the professional chemist, if they wish for information regarding the composition of their soils.

Under the term *surface-soil*, we mean that portion of soil which is on the surface; whilst by *subsoil* we mean that which is below the former, and out of the reach of the ordinary plough.

CHEMICAL COMPOSITION OF CERTAIN SOILS, ACCORDING TO ANALYSIS.

1. Surface-soil (A) a good loamy soil, from the vicinity of Gandersheim. It is remarkable for producing uncommonly fine red clover when manured with gypsum. (B) is an analysis of the subsoil. 100 parts contain:—

	(A)	(B)
Silica, with fine siliceous sand -	91·331	93·883
Alumina - - - - -	1·344	1·944
Peroxide of iron, with a little protoxide - - - - -	1·562	2·226
Peroxide of manganese - -	0·082	0.320
Magnesia and silica, in combination with sulphuric acid and humus - - - - -	0·800	0·720
Magnesia, with silica and humic acid combined - -	0·440	0·340
Potash, in combination with silica	0·156	0·105
Soda, principally in combination with silica, and a little as common salt - - - -	0·066	0·060
Phosphoric acid - - -	0·098	0·190
Sulphuric acid in combination with lime - - - -	0·111	0·012
Chlorine (in common salt) -	0 012	0·012
Humus, with traces of azotised matter - - - - -	4·100	0·184
	100·000	100·000

An inspection of the above analyses will show that the soil contains a very small proportion of salts of sulphuric acid—a circumstance which accounts for the favourable action of gypsum upon it.

2. The surface-soil (A) is a fine-grained loamy soil from Gandersheim, distinguished for the remarkably large crops of beans, peas, tares, &c., which it produces when manured with gypsum. (B) is the analysis of the subsoil. 100 parts contain:—

	(A)	(B)
Silica, with fine siliceous sand -	90·221	92·324
Alumina - - -	2·106	2·262
Peroxide and protoxide of iron -	3·951	2·914
Peroxide of manganese - -	0·960	2·960
Lime, principally combined with phosphoric acid and humus -	0·539	0·532
Magnesia, with silicate of potash, &c. - - -	0·730	0·340
Potash - - - - -	0·067	0·304
Soda - - - -	0·010	a trace
Phosphoric acid - - -	0·367	0·122
Sulphuric acid (in gypsum) -	a trace	0·010
Chlorine (in common salt) -	0·100	0·004
Humus and azotised matter -	0.900	——
Loss - - - -	0·140	0·228
	100·000	100·000

The analysis of this soil shows, that, with the exception of gypsum, every ingredient is present which is requisite for the nourishment of leguminous plants. Hence it is that gypsum exerts such a favourable influence upon it.

3. Surface-soil (A) a strong loamy sand, from Brunswick. (B) the analysis of the subsoil. 100 parts contain:—

	(A)	(B)
Silica, with coarse siliceous sand	95·698	96·880
Alumina - - -	0·504	0·890
Peroxide and protoxide of iron -	2·496	1·496
Peroxide of manganese - -	a trace	a trace
Lime - - - -	0·038	0.019
Magnesia - - -	0·147	0·260
Potash and soda, the greatest part in combination with silica	0·090	0·079
Phosphate of iron - -	0·164	0·110

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[*] In some parts of the grand-duchy of Hesse, where wood is scarce and dear, it is customary for the common people to club together and build baking ovens, which are heated with straw instead of wood. The ashes of this straw are carefully collected and sold every year at very high prices. The farmers there have found by experience that the ashes of straw form the very best manure for wheat; although it exerts no influence on the growth of fallow-crops (potatoes or the leguminosæ, for example.) The stem of wheat grown in this way possesses an uncommon strength. The cause of the favourable action of these ashes will be apparent, when it is considered that all corn-plants require silicate of potash; and that the ashes of straw consist almost entirely of this compound.—Ed.

[†] If sulphate of iron be employed, it ought not to be added in great excess, and the urine must be exposed to the air for some time after, for the purpose of converting the iron into the peroxide. A salt of the protoxide of iron is injurious to vegetation.

[*] One of the causes of the advantages produced by subsoil ploughing is, that it exposes the soil to the disintegrating influences of the atmosphere. Hence it is that the subsoil plough is so beneficial in siliceous soils, and exerts no apparent effect upon those which contain much clay. The former disintegrate and liberate their potash both with facility and rapidity; whilst the disintegration of the latter proceeds with slowness, and no appreciable effects are produced. (*See Journal of the Agricultural Society*, vol. ii., p. 27.) It is probable, however, that if the land received a dressing of lime after subsoil ploughing, the effects would be produced more rapidly.—Ed.

	(A)	(B)
Sulphuric acid (in gypsum)	0·007	a trace
Chlorine (in common salt)	0·010	a trace
Humus	0·846	0·226
	100·000	100·000

This soil was much improved by manuring with lime and ashes. It was then found well fitted for clover, beans, and peas.

4. Surface-soil (A) a loamy sand, from the environs of Brunswick. (B) analysis of the subsoil at the depth of 3 feet. 100 parts contain:—

	(A)	(B)
Silica and fine siliceous sand	94·724	97·340
Alumina	1·638	0.806
Protoxide and peroxide of iron with manganese	1·960	1·201
Lime	1·028	0·296
Magnesia	a trace	0·095
Potash and soda	0·077	0·112
Phosphoric acid	0·024	0·015
Gypsum	0·010	a trace
Chlorine of the salt	0·207	a trace
Humus	0·512	0·135
	100·000	100·000

This soil produces luxuriant crops of lucerne and sainfoin, as well as of all other plants the roots of which penetrate deeply into the ground. The reason is apparent. The subsoil contains magnesia, which is wanting in the surface-soil.

5. Surface-soil (A) a loamy sand, from the environs of Brunswick. (B) analysis of the subsoil at a depth of 2 feet. 100 parts contain:—

	(A)	(B)
Silica, with coarse siliceous sand	95·843	95.190
Alumina	0·600	1·600
Protoxide and peroxide of iron	1·800	2·200
Peroxide of manganese	a trace	a trace
Lime, in combination with silica	0·038	0.455
Magnesia in do. do.	0·006	0·160
Potash and soda	0·005	0·004
Phosphate of iron	0·198	0·400
Sulphuric acid	0·002	a trace
Chlorine	0·006	0·001
Humus soluble in alkalies	1·000	. . .
Humus insoluble in alkalies	0·502	. . .
	100·000	100·000

This soil is characterised by its great sterility. White clover could not be made to grow upon it. The obvious cause of its poverty is a deficiency of lime, magnesia, potash, and gypsum; for we find that the fertility of the soil was much increased by manuring it with marl. The white clover, which formerly had refused to grow on this soil, now grew upon it with much luxuriance. The aridity of the soil could not have been the cause of its sterility, for the stiff nature of the subsoil on which it rested prevented a deficiency of moisture.

6. Surface-soil (A) a loamy land from the environs of Brunswick. (B) the analysis of the subsoil, at a depth of 2 feet. 100 parts contain:—

	(A)	(B)
Silica, with fine siliceous sand	94·998	96.490
Alumina	0·610	1·083
Protoxide and peroxide of iron	1·080	1.472
Peroxide of manganese	0.268	0·400
Lime, in combination with silica	0·141	0.182
Magnesia, *idem*	0·208	0·205
Potash, *idem*	0·050	0·070
Soda, *idem*	0·044	0·050
Phosphate of iron	0·086	0·030
Gypsum	0·041	0·005
Common salt	0·004	0·003
Humus soluble in alkalies	0·400	0·010
Humus accompanied by azotised matter	2.070	. . .
Resinous matter	a trace	. . .
	100.000	100.000

This soil is by no means remarkable for its sterility, but is decidedly improved by manuring with burned ferruginous loam. It is, however, rendered still better by the use of burned marl—a manure which is rich in iron, potash, gypsum, and phosphate of lime. The marl does not exert so favourable an action when applied in its natural state; but the heat liberates the potash from the insoluble compound which it forms with silica.

7. Surface-soil (A) a loamy sand, from Brunswick. (B) analysis of the subsoil at a depth of 1½ feet. 100 parts contain:—

	(A)	(B)
Silica, with fine siliceous sand	92·980	96·414
Alumina	0·820	1·000
Protoxide and peroxide of iron	1·666	1·370
Peroxide of manganese	0.188	0·240
Lime, combined with silica	0·748	0·364
Magnesia, *idem*	0·168	0·160
Potash, *idem*	0·065	0·045
Soda, *idem*	0·130	0·082
Phosphate of iron	0·246	0·043
Sulphuric acid contained in gypsum	a trace	0·005
Chlorine	a trace	0·007
Humus soluble in alkalies	0·764	0·270
Humus, with azotised organic remains	2·225	. . .
	100·000	100·000

The soil when manured with gypsum is very favourable to the production of leguminous plants and red clover. But it is very remarkable, on account of the rust which always attacks the corn plants which may be grown upon it. This rust and mildew (*uredo linearis, puccinia graminis*) is a disease which attacks the stem and leaves, and is quite different from the *brand* (*uredo glumarum*) which appears on the seeds and organs of reproduction. Rust is most frequently detected on plants growing on soils which contain bog-ore or turf-iron ore. According to Sprengel, rust contains phosphate of iron, to which this chemist ascribes the origin of the disease. It is very possible that other causes may operate in the production of similar diseases.

8. Soil, a fine-grained loamy marl, from the vicinity of Schoningen. It produces corn, which is, however, very liable to blight. 100 parts contain:—

Silica, with siliceous sand	93·870
Alumina	1·248
Protoxide and peroxide of iron	1·418
Peroxide of manganese	0·360
Lime (principally carbonate)	0·546
Magnesia, *idem*	0·560
Potash, with silica	0·050
Soda with silica	0·040
Phosphate of iron	0·246
Sulphuric acid with lime	0·027
Carbonic acid, with lime and magnesia	1·145
Humus soluble in alkalies	0·400
Humus	0·090
	100·000

It will be observed that a considerable quantity of phosphate of iron is contained in this soil, and the corn which grows upon it is, as in the former case, disposed to rust.

9. Surface-soil (A) a loamy soil, from Brunswick, remarkable on account of producing buck-wheat, which is exceedingly poor in the grain. (B) analysis of the subsoil at a depth of 1½ foot. 100 parts contain:—

	(A)	(B)
Silica, with coarse siliceous sand	95·114	92·458
Alumina	1·080	2·530
Protoxide and peroxide of iron	1·900	2·502
Protoxide and peroxide of manganese	0·320	0·920
Lime, in combination with silica	0·380	0·710
Magnesia, *idem*	0·300	0·551
Potash, with silica	0·020	0.120
Soda	0.004	0·034
Phosphate of iron	0·052	0·175
Sulphuric acid with lime	0·006	a trace
Chlorine (in common salt)	0·005	a trace
Humus soluble in alkalies	0·619	. . .
Humus	0·200	. . .
	100·000	100·000

By manuring the land with wood ashes, the soil is enabled to produce buck-wheat, with rich grain; the leguminous plants also thrive luxuriantly upon it. This increased fertility is due to the ashes, by means of which both potash and phosphates are supplied to the land.

10. Subsoil of a loamy, sandy soil, from Brunswick. It is remarkable for having produced excellent crops of hops for a long series of years. 100 parts, by weight, consist of:—

Silica, with siliceous sand	95.660
Alumina	1.586
Protoxide and peroxide of iron	1.616
Peroxide of manganese	0.240
Lime, in combination with silica	0.083
Magnesia	0.080
Potash	0.030
Soda	0.220
Phosphoric acid	0.039
Sulphuric acid	0.003
Chlorine	a trace
Humus soluble in alkalies	0.080
Humus	0.360
	100.000

Although the hops contain a large quantity of potash, soda, phosphoric acid, sulphuric acid, lime, and magnesia, yet we do not find that these exist in the soil in superabundant quantity. Nor is it necessary that they should, for the roots of the hops penetrate 8 or 10 feet deep into the soil, and search out the materials fitted to nourish the plants. Hence it is that hops thrive well on soils comparatively poor in their proper ingredients. The same is the case with all plants of a similar nature, the roots of which possess a tendency to extend in search of food; we see this particularly in lucerne and sainfoin.

SOILS OF HEATHS.

11. Soil of a heath converted into arable land, in the vicinity of Brunswick. It is naturally sterile, but produces good crops when manured with lime, marl, cow-dung, or the ashes of the heaths which grow upon it.

Silica, and coarse siliceous sand	71.504
Alumina	0.780
Protoxide and peroxide of iron, principally combined with humus	0.420
Peroxide of manganese, *idem*	0.220
Lime, *idem*	0.134
Magnesia, *idem*	0.032
Potash and soda, principally as silicates	0.058
Phosphoric acid, (principally as phosphate of iron)	0.115
Sulphuric acid (in gypsum)	0.018
Chlorine (in common salt)	0.014
Humus soluble in alkalies	9.820
Humus, with vegetable remains	14.975
Resinous matters	1.910
	100.000

Ashes of the soil of the heath, before being converted into arable land:—

Silica, with siliceous sand	92.641
Alumina	1.352
Oxides of iron and manganese	2.324
Lime, in combination with sulphuric and phosphoric acids	0.929
Magnesia, combined with sulphuric acid	0.283
Potash and soda (principally as sulphates and phosphates	0.564
Phosphoric acid, combined with lime	0.250
Sulphuric acid, with potash, soda and lime	1.620
Chlorine in common salt	0.037
	100.000

12. Surface-soil of a fine-grained loam, from the vicinity of Brunswick. It is remarkable from the circumstance, that not a single year passes in which corn plants are cultivated upon it without the stem of the plants being attacked by rust. Even the grain is covered with a yellow rust, and is much shrunk. 100 parts of the soil contain:—

Silica and fine siliceous sand	87.859
Alumina	2.652
Peroxide of iron with a large proportion of protoxide	5.132
Protoxide and peroxide of manganese	0.840
Lime principally combined with silica	1.459
Magnesia, *idem*	0.280
Potash and soda, *idem*	0.090
Phosphoric acid in combination with iron	0.505
Sulphuric acid in combination with lime	0.068
Chlorine in common salt	0.006
Humus	1.109
	100.000

This soil does not suffer from want of drainage: it is well exposed to the sun, is in an elevated situation, and in a good state of cultivation. In order to ascertain whether the rust was due to the constituents of the soil, (phosphate of iron?) or to certain fortuitous circumstances unconnected with their operation, a portion of the land was removed to another locality, and made into an artificial soil of fifteen inches in depth. Upon this barley and wheat were sown; but it was found, as in the former case, that the plants were attacked by rust, whilst barley growing on the land surrounding this soil was not at all affected by the disease. From this experiment it follows, that certain constituents in the soil favour the developement of rust.

13. Soil of a heath, which had been brought into cultivation in the vicinity of Brunswick. The analysis was made before any kind of crops had been grown upon it. Corn-plants were first reared upon the new soil, but were found to be attacked by the rust, even on those parts which had been manured respectively with lime, marl, potash, wood ashes, bone-dust, ashes of the heath plant, common salt and ammonia. 100 parts contain:—

Silica with coarse siliceous sand -	51·337
Alumina - - - - -	0·528
Protoxide and peroxide of iron in combination with phosphoric and humic acids	0·398
Protoxide and peroxide of manganese -	0·005
Lime in combination with humus -	0·230
Magnesia *idem* - - - -	0·040
Potash and soda - - -	0·010
Phosphoric acid - - - - -	0·066
Sulphuric acid - - - -	0·022
Chlorine - - - - - -	0·014
Humus soluble in alkalies - - -	13·210
Resinous matters - - -	2·040
Coal of humus and water - -	32·100
	100·000

The next analysis represents the soil after being burnt. 100 parts by weight of the soil left after ignition only 50 parts. 100 parts of these ashes consisted of:—

Silica and siliceous sand - - -	95·204
Alumina - - - - : -	1·640
Peroxide of iron - - - - - -	1 344
Peroxide of manganese	0·080
Lime in combination with sulphuric acid	0·544
Magnesia combined with silica - -	0·465
Potash and soda - - - - -	0·052
Phosphoric acid (principally as phosphate of iron - - - - - - - -	0·330
Sulphuric acid - - - - - - -	0·322
Chlorine - - - - - -	0·019
	100·000

By comparing this analysis with the one which has preceded it, an increase in certain of the constituents is observed, particularly with respect to the sulphuric acid, potash, soda, magnesia, oxide of iron, oxide of manganese, and alumina. From this it follows, that the humus, or in other words, the vegetable remains, must have contained a quantity of these substances confined within it, in such a manner that they were not exhibited by analysis.

Oats and barley were sown on this land the second year after being reclaimed, and both suffered much from rust, although different parts of the soil were manured with marl, lime and peat-ashes; whilst other portions were left without manure. In the first year, all the different parts of the field produced potatoes, but they succeeded best in those divisions which had been manured with peat-ashes, lime and marl. In the second year, oats mixed with a little barley were sown upon the soil; and the straw was found to be strongest on the parts treated with peat-ashes, lime, marl, and ashes of wood. Red clover was sown on the third year; it appeared in best condition on those portions of the soil manured with marl and lime. Upon the divisions of the field which had been left without manure, as well as on those manured with bone-dust, potash, ammonia and common salt, the clover scarcely appeared above ground. The divisions of the field, which had been manured in the first year with peat-ashes, ammonia, and ashes of wood, were sown with buckwheat after the removal of the first crop of clover. The buckwheat succeeded very well on all the divisions, yet a marked difference was perceptible in favour of the portion treated with ammonia. These experiments show us, that a dressing of lime did not completely remove from the soil its tendency to impart rust to the plants grown upon it. Nevertheless it is highly probable, that as soon as the protoxide of iron became converted into the peroxide by exposure to the atmosphere, lime would possess more power in decomposing the phosphate of iron.

14. Subsoil of a loamy soil in the vicinity of Brunswick. It is remarkable from the circumstance that sainfoin cannot be cultivated upon it more than two or three years in succession. The portion analysed was taken from a depth of five feet. 100 parts contained:—

Silica with very fine siliceous sand -	90·035
Alumina - - - - - - -	1·976
Peroxide of iron - - - - - -	4·700
Protoxide of iron - - - - - -	1·115
Protoxide and peroxide of manganese -	0·240
Lime - - - - - - - -	0·022
Magnesia - - - - - - -	0·115
Potash and soda - - - - - -	0·300
Phosphoric acid, combined with iron -	0·098
Sulphuric acid (the greatest part in combination with protoxide of iron) - -	1·399
Chlorine - - - - -	a trace
	100.000

Now the results of the analysis give a sufficient account of the failure of the sainfoin. The soil contains above one per cent. of sulphate of protoxide of iron (*green vitriol* of commerce,) a salt which exerts a poisonous action upon plants. Lime is not present in quantity sufficient to decompose this salt. Hence it is that sainfoin will not thrive on this soil, nor indeed lucerne, or any other of the plants with deep roots. The evil cannot be obviated by any methods sufficiently economical for the farmer, because the soil cannot be mixed with lime at a depth of five or six feet. For many years experiments have been made in vain, in order to adapt this soil for sainfoin and lucerne, and much expense incurred, which could all have been saved, had the soil been previously analysed. This example affords a most convincing proof of the importance of chemical knowledge to an agriculturist.

15. Surface soil (A) of a sandy loam in the vicinity of Brunswick, celebrated for its beautiful crops of clover, rye, potatoes, and barley. The clover must, however, always be manured with gypsum. (B) is an analysis of the subsoil at the depth of 1½ foot. 100 parts contain:—

	(A)	(B)
Silica with coarse siliceous sand	94·274	95·146
Alumina - - - -	1.560	1·416
Peroxide of iron with a little phosphoric acid - - -	2·496	2·528
Peroxide of manganese -	0·240	0·320
Lime - - - - -	0·400	0·297
Magnesia - - : -	0·230	0·221
Potash and soda - - -	0·102	0·060
Sulphuric acid - - -	0·039	0·012
Chlorine - - - -	0·005	a trace
Humus soluble in alkaline carbonates - - - - -	0·444	. .
Humus - - - - -	0·210	. .
	100·000	100·000

The best property of this soil is, that its inferior layers are nearly of the same composition as the superior, as far as the inorganic constituents are concerned. It is a soil upon which the plants mentioned above will seldom fail; and as it possesses a very good mixture to the depth of four or five feet, it would, doubtless, produce lucerne also.

16. Surface-soil (A) of a sandy loam in the vicinity of Brunswick. It produces excellent crops of oats and clover, when the latter is manured with gypsum. (B) Analysis of the subsoil taken from a depth of 1½ foot. 100 parts contain:—

	(A)	(B)
Silica and siliceous sand -	94·430	89·660
Alumina - - - - -	1·474	0·980
Peroxide of iron with a little phosphoric acid - -	2·370	7·616
Peroxide of manganese -	a trace	a trace
Lime, principally combined with silica - - - - -	0·680	0·954
Magnesia, *idem* - - -	0·290	0·520
Potash - - - - -	0·190 }	0·150
Soda - - - - - -	0·010 }	
Sulphuric acid - - - -	a trace	a trace
Chlorine - - - - -	0·015	a trace
Humus - - - - -	0·541	0·120
	100·000	100·000

Both the surface and the sub-soil contain only traces of sulphuric acid. Hence the application of gypsum is attended with great benefit. Without doubt, marl and lime would be found of essential service.

17. Soil from the environs of Brunswick, consisting principally of sand, and eminently remarked for its sterility. It was, however, much improved by manuring it with marl which contained 24 per cent. of lime, together with magnesia, manganese, potash, soda, gypsum, and common salt. 100 parts of the soil contained:—

Silica and siliceous sand - - -	95·841
Alumina - - - - - -	0·600
Protoxide and peroxide of iron - -	1·800
Peroxide of manganese - - -	a trace
Lime in combination with silica - -	0·038
Magnesia, *idem* - - - -	0·006
Potash - - - - - - -	0·002
Soda - - - - - -	0 003
Phosphoric acid combined with iron -	0·198
Sulphuric acid - - - - -	0·002
Chlorine - - - - - -	0·006
Humus - - - - - -	1·504
	100·000

Here another proof is presented, that a soil may be very rich in humus and yet be very poor as regards fertility. By means of the marl, the inorganic ingredients of the plants are furnished to the soil, which contains them in very small quantity.

18. The soil of a very fertile loam from the vicinity of Walkenried. 100 parts contain:—

Silica, with coarse-grained silicious sand	88·456
Alumina - - - - - -	0·650
Peroxide and protoxide of iron, accompanied by much magnetic iron sand - -	5·608
Peroxide of manganese - - -	0·560
Carbonate of lime - - - - -	1·063
Carbonate of magnesia - - -	1·688
Potash combined with silica - - -	0·04[illegible]
Soda combined with silica - -	0·012
Phosphate of lime - - - -	0·035
Sulphate of lime - - - -	a trace
Common salt - - - - -	0·[illegible]65
Humus soluble in alkalies - - -	0·550
Humus with several azotised organic remains - - - - -	1·333
	100·000

Gypsum acts most excellently upon this land. The soils in the southern range of the Harz mountains are particularly remarked for containing more magnesia than lime. Even the different varieties of marl contain a considerable quantity of magnesia. Thus, in a specimen of marl obtained from the vicinity of Walkenried, I obtained 55½ per cent. carbonate of lime, and 30½ per cent. carbonate of magnesia; in another 41 per cent. lime, and 11 per cent. magnesia; and in a third, 47½ per cent. lime, and 13½ per cent. magnesia. Most of these soils contain also ½—1 per cent. of gypsum, and ½—1 per cent. phosphate of lime, and are, therefore, well fitted for manuring other lands.

19. Subsoil of a loam from a depth of 1½ foot. It occurs in the vicinity of Brunswick. The surface-soil is remarkable on account of producing beautiful red clover on being manured with gypsum; although the soil itself contains only traces of lime, magnesia, potash, and phosphoric acid. 100 parts of the subsoil contained:—

Silica and coarse siliceous sand	88·980
Alumina	2·240
Protoxide and peroxide of iron	3·840
Peroxide of manganese	a trace
Carbonate of lime	2·720
Carbonate of magnesia	0·600
Potash and soda	0·095
Phosphate of lime	1.510
Sulphate of lime	a trace
Common salt	0·015
	100·000

At a greater depth than the subsoil of which the analysis is here given, the soil passes into marl, which contains 20½ per cent. of carbonate of lime. The sulphuric acid deficient in the soil was supplied by means of the gypsum.

SOILS IN THE KINGDOM OF HANOVER.

20. (A) Analysis of a barren heath-soil from Aurich in Ostfriesland; (B) a sandy soil containing much humus but also sterile; (C) a sandy soil possessing the same characters as B. 100 parts contained:—

	(A)	(B)	(C)
Silica and coarse siliceous sand	95·778	85·973	96·721
Alumina	0·320	0·320	0·370
Protoxide and peroxide of iron	0·400	0·440	0·480
Peroxide of manganese	a trace	a trace	a trace
Lime	0·286	0.160	0·005
Magnesia	0·060	0·240	0·080
Soda	0·036	0·012	0·036
Potash	a trace	a trace	a trace
Phosphoric acid	a trace	a trace	a trace
Sulphuric acid	a trace	a trace	a trace
Chlorine in common salt	0·052	0·019	0·058
Humus	0·768	0·636	0·800
Vegetable remains	2·300	8·200	1·450
	100·000	100·000	100·000

21. Analysis of the clayey subsoil of a moor, which, after being burned, is used as a manure to the above soils, A, B, C. 100 parts contain:—

Silica and siliceous sand	87·219
Alumina	4·200
Peroxide of iron with a little phosphoric acid	5·200
Peroxide of manganese	0·310
Lime	0·320
Magnesia	0·380
Potash principally combined with silica	0·130
Soda principally combined with silica	0·274
Sulphuric acid combined with lime, magnesia, and potash	0·965
Chlorine	0·002
Humus	1·000
	100·000

By comparing this analysis with that of the three soils which have preceded, it will be observed that this subsoil is fitted to impart to them those mineral ingredients in which they are deficient.

22. Surface soil of a barren heath in the vicinity of Walsrode in Luneberg. 100 parts by weight contain:—

Silica and siliceous sand	92·216
Alumina	0·266
Peroxide of iron	0·942
Protoxide of iron	0·394
Peroxide of manganese	a trace
Lime, in combination with silica, sulphuric acid, and humus	1·653
Magnesia, in combination with silica	0·036
Potash, principally in combination with silica	0·038
Soda	a trace
Phosphoric acid	a trace
Sulphuric acid	0·051
Chlorine	a trace
Humus, soluble in alkaline carbonates	2·084
Humus	1·900
Resinous matter	0·420
	100·000

This soil contains a large quantity of protoxide of iron, which, together with a deficiency of phosphoric acid, is the cause of its sterility. But when this land was manured with the ashes of peat, it was rendered much more fertile. The ashes used for this purpose were found to contain in 100 parts:—

Silica, with siliceous sand	96·352
Alumina	1·859
Peroxide and protoxide of iron, with a little phosphoric acid	1·120
Peroxide of manganese	0·160
Lime	0·112
Magnesia	0·141
Potash	0·093
Soda	0.007
Sulphuric acid	0·152
Chlorine	0·004
	100·000

The ashes, on exposure to the air, absorbed ammonia.

23. Analysis of a very fertile loamy soil from Göttingen. It is very rich in humus, and produces beautiful crops of peas, beans, lucerne, and beet. The sieve separates from 100 parts of the soil:—

Small stones, principally limestone	1
Quarzy sand, with a little magnetic iron sand	15
Earthy part	84
	100

100 parts of the soil, freed from stones, consists of:—

Silica, and fine siliceous sand	83·298
Alumina, combined with silica	1·413
Alumina, partly in combination with humus	3·715
Peroxide and protoxide of iron, in combination with silica	0.724
Peroxide and protoxide of iron, partly free and partly in combination with humus	2·244
Peroxide and protoxide of manganese	0.280
Lime, with coal of humus, sulphur, and phosphoric acid	1·814
Magnesia, combined with silica	0·422
Magnesia, combined with humus	0·400
Potash	0·003
Soda	0·001
Phosphoric acid	0·166
Sulphuric acid	0·069
Chlorine	0·002
Carbonic acid (as carbonate of lime)	0·440
Humus, soluble in alkalies	0·789
Humus, with a little water	3·250
Nitrogenous matter	0·960
Resinous matter	a trace
	100·000

The subsoil is of the same composition as

the surface, with this difference only, that it contains more potash, soda, and chlorine,* and is interspersed with fragments of fresh-water shells. Hence it is that the soil produces the deep-rooted plants in such luxuriance.

24. Soil of a sterile moor, which had been burned three times, and upon which buckwheat had been cultivated. 100 parts contained:—

Humus, soluble in alkalies	9·250
Vegetable remains, charcoal, quarzy sand, and earthy particles	90·750
	100·000

100 parts by weight left, after ignition, 10 parts of ashes. 100 parts of these ashes consisted of:—

Silica and siliceous sand	79·600
Alumina	6·288
Peroxide of iron	0·857
Peroxide of manganese	0·400
Carbonate of lime	7·652
Carbonate of magnesia	1·640
Potash	0·080
Soda	0·028
Phosphoric acid	0·215
Sulphate of lime (gypsum)	3·235
Chlorine	0·005
	100·000

Soils such as this, after having been burned several times, and made to produce buckwheat, are completely deprived of their potash and soda; and in consequence of this are rendered quite barren. Hence it is that ashes of wood exert such an astonishing effect upon them.

25. Analysis of a very fertile loamy sand, from Osnabrück, near Rotherfeld. It is remarkable for being manured only once every 10 or 12 years, and bears beautiful wheat as the last crop. 100 parts contain:—

Silica, with coarse siliceous sand	86·200
Alumina	2·000
Peroxide and protoxide of iron, with a little phosphoric acid	2·900
Peroxide of manganese	0·100
Carbonic acid, and a little phosphate of lime	4·160
Carbonate of magnesia	0·520
Potash and soda	0·035
Phosphoric acid	0·020
Sulphuric acid	0·021
Chlorine	0·010
Humus, soluble in alkaline carbonates	0·544
Humus	3·370
Nitrogenous matter	0·120
	100·000

The soil in question lies on the southern exposure of a hill, which consists of layers of limestone and marl. The rain-water penetrates through these layers, and becomes saturated with the soluble salts contained in them, such as potash, gypsum, common salt, lime, magnesia, and saltpetre. It afterwards reaches the soil, and manures it with these ingredients. It is only in this manner that we are enabled to explain the fertility of this soil; for, reasoning from its chemical composition, we would be induced, *à priori*, to suppose that it would be barren. At the base of this hill, certain portions of the land are covered with calcareous tuff, containing the above salts: a fact which proves that the water which penetrates through the soil must also contain them in solution. The large proportion of humus exhibited by the analysis depends upon the nature of the manure to which it was treated.

26. Analysis of a heavy alluvial soil, from Norden. 100 parts contain:—

Silica, and very fine siliceous sand	84·543
Alumina	3·458
Peroxide of iron	3·488
Peroxide of manganese	0·560
Lime	0·319
Magnesia	0·740
Potash	a trace
Soda, in combination with silica	6·004
Phosphoric acid, in combination with lime	0·260
Sulphuric acid	0·008
Chlorine	0·008
Humus, soluble in alkalies	0·416
Humus and nitrogenous matter	0·196
	100·000

The portion of the soil subjected to analysis was taken at a depth of 10 inches, from a field which had received no manure for several years. It had previously produced in succession barley, beans, wheat, and grass, the latter for two years. The soil is remarkable, in a chemical point of view, from the large quantity of soda which it contains. Although the sulphuric acid, chlorine, and potash are present in small quantity, yet this does not present any barrier to the developement of the plants, as the surface-soil is 18 inches in depth.

27. Analysis of a heavy alluvial soil in the vicinity of Norden. 100 parts contain:—

Silica, and very fine siliceous sand	79·174
Alumina	3·016
Peroxide of iron	4·960
Peroxide of manganese	0·600
Carbonate of lime	2·171
Carbonate of magnesia	2·226
Potash, in combination with silica	0·025
Soda, *idem*	6·349
Phosphoric acid	0·534
Sulphuric acid	a trace
Chlorine	0·005
Humus, soluble in alkalies	0·782
Humus with nitrogenous matter	0·158
	100·000

The specimen for analysis was taken at a depth of 10 inches from the surface of a field, which had been manured five years previously, and had produced since that time rape, rye, wheat, and beans. The crops of all these were plentiful, and of excellent quality. It is singular that this soil, which contains such a small proportion of gypsum, should be adapted for the cultivation of beans, and must be ascribed to the depth of the surface-soil. Yet, notwithstanding this, gypsum would form a beneficial manure to the land.

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* The portion of the suface-soil subjected to analysis was taken from the field after long-continued rain. Hence the small quantity of salts of potash and soda.

28. Analysis of a very fertile alluvial soil, from Honigpolder; no manure had ever been applied to it. 100 parts contain:—

Siliceous sand separated by the sieve	4·5
Earthy portion of the soil	95·5
	100.0

100 parts of the latter consisted of:—

Silica, and fine siliceous sand	64·800
Alumina	5·700
Peroxide of iron	6·100
Peroxide of manganese	0·090
Lime	5·880
Magnesia	0·840
Potash, principally in combination with silica	0·210
Soda, *idem*	0·393
Phosphoric acid combined with lime	0·430
Sulphuric acid, *idem*	0·210
Chlorine (in common salt)	0·201
Carbonic acid, combined with lime	3·920
Humus soluble in alkalies	2·540
Humus	5·600
Nitrogenous matter	1·582
Water	1·504
	100·000

Corn has been cultivated for seventy years upon this soil, which has never received dung or any other kind of manure; it is, however, occasionally fallowed. The subsoil retains the same composition as the surface-soil for a depth of 6—12 feet, so that it may be considered inexhaustible. When one portion of the soil is rendered unfitted for use, the inferior layers are brought up to the surface.

29. Analysis of a soil from Rahdingen, near Balje. In this case the sea has assisted in the formation of the soil. The field yielded beautiful corn after being manured with stable dung, being particularly remarked for its fine crops of wheat, beans, and winter barley. 100 parts contain:—

Silica, siliceous sand, and silicates	87·012
Alumina	4·941
Peroxide of iron	2·430
Peroxide of manganese	0·192
Lime	0·292
Magnesia	0·145
Potash and soda soluble in water	0·005
Phosphoric acid	0·114
Sulphuric acid	0·074
Chlorine (in common salt)	0.003
Humus, soluble in alkaline carbonates	0·658
Humus	2·668
Nitrogenous matter	1·412
Water	0·042
	100·000

30. Soil of a field remarkable for producing large crops of hemp and horse-radish. 100 parts consisted of:—

Silica and siliceous sand	84.021
Alumina	4·498
Peroxide of iron	5·120
Peroxide of manganese	2·080
Lime	0·942
Magnesia	1·740
Potash	0·050
Soda	0·012
Phosphoric acid	0·482
Sulphuric acid	0·012
Chlorine	0·008
Humus soluble in alkaline carbonates	0·897
Humus and nitrogenous matter	0·138
	100·000

31. Surface-soil of a field near Drackenburg; it produces very bad red clover. 100 parts contain:—

Silica, with very fine siliceous sand	92·014
Alumina	2·652
Peroxide of iron	3·192
Peroxide of manganese	0·480
Lime	0·243
Magnesia	0·700
Potash combined with silica	0.125
Soda, *idem*	0·026
Phosphoric acid, in combination with lime	0·078
Sulphuric acid	a trace
Chlorine	a trace
Humus and nitrogenous matter	0·150
Humus soluble in alkaline carbonates	0·340
	100.000

The cause that clover will not flourish on this soil is probably due to the deficiency of gypsum and common salt.

32. Surface-soil of a field near Paddingbuttel. This field is particularly adapted for the growth of red clover. 100 parts consist of:—

Silica and siliceous sand	93·720
Alumina	1·740
Peroxide of iron	2·060
Peroxide of manganese	0·320
Lime	0·121
Magnesia	0·700
Potash, principally in combination with silica	0·062
Soda, *idem*	0·109
Phosphoric acid	0·103
Sulphuric acid	0·005
Chlorine (in common salt)	0·050
Humus soluble in alkaline carbonates	0·890
Humus with nitrogenous matter	0·120
	100·000

SOILS IN BOHEMIA.

33. Surface-soil of a very fertile field in the province of Dobrawitz and Lautschin. 100 parts gave

Siliceous sand, with much magnetic iron sand	4·286
Earthy part separated by the sieve	95·714
	100·000

An aqueous infusion of the soil contained gypsum, common salt, magnesia, and humus. 100 parts of the soil gave:—

Silica	89·175
Alumina	2·652
Protoxide and peroxide of iron	3·136
Peroxide of manganese	0·320
Lime	1·200
Magnesia	1·040
Potash, in combination with silica	0·075
Soda, *idem* (principally)	0·354
Phosphoric acid, in combination with lime	0·377
Sulphuric acid, *idem*	0·081
Chlorine (in common salt)	0·066
Humus soluble in alkalies	0·920
Humus	0·456
Nitrogenous matter	0·208
	100·000

34 Surface-soil of a very fertile field in the province of Dobrawitz and Lautschin. 100 parts of the earth consisted of:—

Siliceous sand, with a little magnetic iron sand	43·780
Finer part separated by the sieve	56·220
	100·000

100 parts yielded to water 0·175 part of salts, consisting of common salt, gypsum, magnesia, and humic acid. 100 parts, by weight, of the earth consisted of:—

Silica	89·634
Alumina	3·224
Protoxide and peroxide of iron	2·944
Peroxide of manganese	1·160
Lime	0·349
Magnesia	0·300
Potash in combination with silica	0·160
Soda, *idem*	0·428
Phosphoric acid, in combination with lime	0·246
Sulphuric acid, *idem*	0·005
Chlorine (in common salt)	0·012
Humus soluble in alkalies	0·750
Humus	0·340
Nitrogenous matter	0·448
	100·000

35. Analysis of a soil formed by the disintegration of basalt. 100 parts of the earth consisted of:—

Siliceous sand, with very much magnetic iron sand	8·428
Earthy portion of the soil	91·572
	100·000

The aqueous infusion of the earth contained only traces of common salt and gypsum, with humus, lime, and magnesia. 100 parts consisted of:—

Silica	83·642
Alumina	3·978
Protoxide and peroxide of iron	5·312
Peroxide of manganese	0·960
Lime	1·976
Magnesia	0·650
Potash, in combination with silica	0·080
Soda, *idem*	0·145
Phosphoric acid, in combination with lime	0·273
Sulphuric acid, *idem*	a trace
Humus soluble in alkaline carbonates	1·270
Chlorine	a trace
Humus	0·234
Nitrogenous matter	1·480
	100·000

Manure consisting of gypsum, common salt, or ashes of wood, would be highly conducive to the fertility of this land.

SOILS IN THE "MARKGRAFSCHAFT MAHREN."

36. Surface-soil of a field very remarkable for its fertility. The field is called *Haargraben*, and is situated near the village of Nebstein. It has never been manured or allowed to lie fallow, and yet has produced for the last 160 years the most beautiful crops; thus furnishing a remarkable example of unimpaired fertility. 100·000 parts of this soil consisted of:—

Course and fine siliceous sand, with a little magnetic iron sand	35·400
Earthy matter	64·600
	100·000

100 parts of the earth yielded to water 0·010 sulphuric acid, 0·010 chlorine, 0·007 soda, 0·012 magnesia, 0·010 potash, with a little silica, humus, and nitrogenous matter, but no appreciable trace of nitrates. 100 parts of the soil contained:—

Silica	77·209
Alumina	8·514
Peroxide of iron	6·592
Peroxide of manganese	1·520
Lime	0·927
Magnesia	1·160
Potash, principally in combination with silica	0·140
Soda, *idem*	0·640
Phosphoric acid, combined with lime and iron	0·651
Sulphuric acid, combined with lime	0·011
Chlorine (in common salt)	0·010
Humus soluble in alkalies	0·978
Humus	0·540
Nitrogenous matter	1·108
	100·000

It is apparent from the above analysis that, notwithstanding the long period during which this land has been cultivated without manure, it still remains very rich in matters adapted for the nutrition of plants.

SOILS IN HUNGARY.

37. Analysis of a very fertile soil from Esákáng. 100 parts of the earth contained:—

Very fine siliceous sand	2·820
Earthy matter	97·180
	100·000

The aqueous decoction of the soil contained principally gypsum, common salt, silica, magnesia, and humus. 100 parts of the soil yielded:—

Silica	76·038
Alumina	4·654
Peroxide and protoxide of iron	6·112
Peroxide of manganese	0·900
Carbonate of lime	3·771
Carbonate of magnesia	4·066
Potash combined with silica	0·030
Soda combined with silica	1·379
Phosphoric acid, combined with lime	0·546
Sulphuric acid	0·021
Chlorine in common salt	0·015
Humus soluble in alkalies	1·160
Humus	1·100
Nitrogenous organic matter	0·208
	100·000

Subsoil of the same field at a depth of two feet. 100 parts consist of:—

Very fine siliceous sand with scales of mica	2·408
Earth separated by the sieve	97·592
	100·000

100 parts of the earth contain :—

Silica	59·581
Alumina	3·224
Peroxide and protoxide of iron	4·896
Peroxide of manganese	0·720
Carbonate of lime	17·953
Carbonate of magnesia	11·075
Potash combined with silica	0·150
Soda, principally combined with silica	0·891
Phosphoric acid combined with lime	0·846
Sulphuric acid, *idem*	0·004
Chlorine in common salt	0·004
Humus soluble in alkalies	0·536
Humus with nitrogenous organic matter	0·120
	100·000

BELGIUM.

38. Surface-soil of a field distinguished for its fertility. It had received no manure for twelve years previous to the time at which the analysis was executed. The rotation of crops for the latter nine years was as follows :—1. beans, 2. barley, 3. potatoes, 4. winter barley with red clover, 5. clover, 6. winter barley, 7. wheat, 8. oats ; during the ninth year it was allowed to lie fallow. The soil is more clayey than loamy, and of a very fine grain. Water extracted from the soil, 0·013 soda, 0·002 lime, 0·012 magnesia, 0·009 sulphuric acid, 0·003 potash, 0·003 chlorine, with traces of silica and humus. 100 parts contained :—

Silica	64·517
Alumina	4·810
Peroxide and protoxide of iron	8·316
Peroxide of manganese	0·800
Carbonate of lime	9·403
Carbonate of magnesia	10·361
Potash, principally combined with silica	0·100
Soda	0·013
Phosphoric acid	1·221
Sulphuric acid	0·009
Chlorine	0·003
Humus	0·447
	100·000

ENGLAND.

39. Surface-soil of a very fertile sandy field from the vicinity of Tunbridge, Kent, according to Davy. 100 parts consisted of :—

Loose stones and gravel	13·250
Sand and silica	58·250
Alumina	3·250
Peroxide of iron	1·250
Carbonate of lime	4.750
Carbonate of magnesia	0.750
Common salt and extractive matter	0·750
Gypsum	0·500
Matter destructible by heat	3·750
Vegetable fibre	3·500
Water	5·000
Loss	5·000
	100·000

The great Davy, who was convinced of the importance of the inorganic constituents of soils, has omitted to detect the phosphoric acid, potash, soda, and manganese. All of these must have been present in the soil for we are informed that it produced good hops, for which these ingredients are indispensable.

40. A good turnip soil from Holkham, Norfolk, yielded to Davy :—

Siliceous sand	88.888
Silica	1·666
Alumina	1·222
Peroxide of iron,	0·334
Carbonate of lime	7·000
Vegetable and saline matter	0·556
Moisture	0·334
	100·000

In this case also, phosphoric acid, manganese, potash, magnesia, &c., have escaped detection by this acute chemist ; yet doubtless they must be present in the soil, for we are informed that it produces good turnips.

41. An excellent wheat soil from the neighbourhood of West Drayton, Middlesex, according to Davy. 100 parts contained :—

Sand and silica	72·800
Alumina	11·600
Carbonate of lime	11·200
Humus and moisture	4.400
	100·000

This analysis has been executed so imperfectly, that it only conveys a very feeble representation of the nature of the soil. A soil which bears good wheat must contain phosphate of potash, soda, chlorine, and sulphuric acid ; yet none of these are exhibited by the analysis.

42. Surface-soil of a fertile field in the neighbourhood of Bristol. 100 parts contained :—

Silica and siliceous sand	60·000
Alumina	12·000
Peroxide of iron	3·500
Lime (carbonate)	7·500
Magnesia	0·500
Humus	1·250
Saline and extractive matter	0·750
Water	14·500
	100·000

Davy has made several analyses of various fertile soils, and since his time numerous other analyses have been published; but they are all so superficial, and in most cases so inaccurate, that we possess no means of ascertaining the composition or nature of English arable land.

SWEDEN.

43. Surface-soil of a field which produces the most abundant crops, and has never been manured. (Berzelius.) 100 parts consist of:—

Siliceous sand	57·900
Silica	14·500
Alumina	2·000
Phosphates of lime and iron	6·000
Carbonate of lime	11.100
Carbonate of magnesia	1.000
Insoluble extractive matter	1·250
Insoluble extractive matter destructible by heat	4·000
Animal matter	1·600
Resin	0·250
Loss	0·400
	100·000

This great chemist has strangely omitted to detect in the soil potash, soda, chlorine, sulphuric acid, and manganese. As this soil is eminent for its fertility, there cannot be the slightest doubt that all these ingredients must have existed in it in notable quantity.

ISLAND OF JAVA.

44. A very fine-grained loamy soil, coloured yellow by peroxide of iron, consisted of:—

Silica and siliceous sand	67·660
Alumina	13·572
Peroxide and protoxide of iron	10·560
Peroxide of manganese	1·640
Lime	0·912
Magnesia	0·570
Potash, principally in combination with silica	0·030
Soda, *idem*	0·184
Phosphoric acid	0·391
Sulphuric acid	0.038
Chlorine	0·010
Humus	0·368
Water with carbonic acid	4·065
	100·000

WEST INDIES (PORTO RICO.)

45. Surface-soil of a very barren field. 100 parts contained :—

Silica and siliceous sand	70·900
Alumina	6·996
Peroxide and protoxide of iron (much magnetic iron sand)	6·102
Peroxide of manganese	0·200
Lime	2·218
Magnesia	3·280
Potash	0·130
Carbonate of soda	6·556
Phosphoric acid, combined with lime	1·362
Sulphuric acid, combined with lime	0·149
Chlorine in common salt	0·067
Humus, soluble in alkalies	0·540
Humus	1·500
	100·000

This soil is improved by gypsum. Its sterility is due to the excessive quantity of carbonate of soda which is present.

NORTH AMERICA.

46. Surface-soil of alluvial land in Ohio, remarkable for its great fertility. 100 parts consisted of:—

Silica and fine siliceous sand	79·538
Alumina,	7·306
Peroxide and protoxide of iron, (much magnetic iron sand)	5·824
Peroxide of manganese	1·320
Lime	0·619
Magnesia	1·024
Potash, principally combined with silica	0·200
Soda	0·024
Phosphoric acid combined with lime and oxide of iron	1·776
Sulphuric acid, combined with lime	0·122
Chlorine	0·036
Humus, soluble in alkalies	1·950
Nitrogenous organic matter	0·236
Wax and resinous matter	0·025
	100·000

47. (A.) Surface-soil of a mountainous district in the neighbourhood of Ohio. (B.) Analysis of the subsoil. This soil is also distinguished for its great fertility. 100 parts contain :—

	(A)	(B)
Silica, with fine siliceous sand	87·143	94·261
Alumina	5·666	1·376
Peroxide and protoxide of iron	2·220	2·336
Peroxide of manganese	0·360	1·200
Lime	0·564	0.243
Magnesia	0·312	0·310
Potash, principally combined with silica	0·120	0·240
Soda	0·025	
Phosphoric acid	0·060	a trace
Sulphuric acid	0·027	0·034
Chlorine	0·036	a trace
Humus soluble in alkalies	1.304	
Humus	1·072	
Carbonic acid, combined with lime	0·080	
Nitrogenous organic matter	1·011	
	100·000	100·000

In the preceding part of the chapter we have inserted a number of analyses of various soils, as well as the conclusions deduced from them, by means of which the farmer may be enabled to ascertain the manures best adapted for each variety of soil. By inspecting the analyses of the sterile soils, it will be apparent that it is in the power of chemistry to point out the causes of their sterility. The general cause which conduces to the sterility of soils is either the absence of certain constituents indispensable for the growth of plants, or the presence of others which exert an injurious or poisonous action. The analyses are those of Dr. Sprengel,—a chemist who has unceasingly occupied himself for the last twenty years in endeavouring to point out the importance of the inorganic ingredients of a soil for the developement of plants cultivated upon it. He considers as essential all the inorganic bodies found in the ashes of plants. Now, although we cannot coincide with him in the opinion that iron and manganese are indispensable for vegetable life, (for these bodies are found as excrementitious matter only in the bark, and never form a constituent of an organ,) yet we gratefully acknowledge the valuable services which he has rendered to agriculture, by furnishing a natural explanation of the action of ashes, marl, &c., in the improvement of a soil. Sprengel has shown that these mineral manures afford to a soil alkalies, phosphates, and sulphates ; and further, that they can exert a notable influence only on those soils in which they are absent or deficient. In a former chapter of this book I have endeavoured to point out the importance of considering these constituents as intimately connected with the vital processes of the vegetable organism, and have shown that the different families of plants contain unequal quantities of inorganic ingredients. This subject has been left unexamined by Sprengel, yet it is one of much importance; for the application of manures must be regulated by the composition of the plants which are cultivated on any particular soil. Still the composition of the soil must always be kept in view. Thus it would be perfect extravagance to manure certain soils with marl, ashes, or gypsum; whilst, on the contrary, these compounds would produce the most beneficial results on other lands.

In a former part of the work, the principal action of gypsum upon vegetation was ascribed to the decomposition and fixation of the carbonate of ammonia contained in rain-water; but gypsum exerts a twofold action. The power of decomposing carbonate of ammonia, and of fixing the ammonia, is not peculiar to gypsum, but is shared also by other salts of lime (chloride of calcium, for example.) But it acts also as a *sulphate*, and when useful as such cannot be replaced by any other salt of lime which does not contain sulphuric acid.

Hence gypsum can be replaced as a manure only by a mixture of a salt of lime with ammonia, and a salt of sulphuric acid. Sulphate of ammonia can therefore be substituted for gypsum, and exerts a more rapid and effectual action. In France, sulphuric acid has been poured upon the fields after the removal of the crops, and has been found to form a good manure. But this is merely a process for forming gypsum *in situ;* for the soils upon which it is applied contain much lime, which enters into combination with the sulphuric acid. It would certainly be much more advantageous to form sulphate of ammonia by adding the acid to putrefied urine, and to apply this mixture to the field.

APPENDIX TO PART I.

EXPERIMENTS AND OBSERVATIONS ON THE ACTION OF CHARCOAL FROM WOOD ON VEGETATION.—BY EDWARD LUKAS.*

"In a division of a low hot-house in the botanical garden at Munich, a bed was set apart for young tropical plants, but instead of being filled with tan, as is usually the case, it was filled with the powder of charcoal (a material which could be easily procured,) the large pieces of charcoal having been previously separated by means of a sieve. The heat was conducted by means of a tube of white iron into a hollow space in this bed, and distributed a gentle warmth, such as tan communicates, when in a state of fermentation. The plants placed in this bed of charcoal quickly vegetated, and acquired a healthy appearance. Now, as is always the case in such beds, the roots of many of the plants penetrated through the holes in the bottom of the pots, and then spread themselves out; but these plants evidently surpassed in vigour and general luxuriance plants grown in the common way—for example, in tan. Several of them, of which I shall only specify the beautiful *Thunbergia alata*, and the genus *Peireskiæ*, throve quite astonishingly; the blossoms of the former were so rich, that all who saw it affirmed they had never before seen such a specimen. It produced also a number of seeds without any artificial aid, while in most cases it is necessary to apply the pollen by the hand. The *Peireskiæ* grew so vigorously, that the *P. aculeata* produced shoots several ells in length, and the *P. grandifolia* acquired leaves a foot in length. These facts, as well as the quick germination of the seeds which had been scattered spontaneously, and the abundant appearance of young *Filices*, naturally attracted my attention, and I was gradually led to a series of experiments, the results of which may not be uninteresting; for, besides being of practical use in the cultivation of most plants, they demonstrate also several facts of importance to physiology. The first experiment which naturally suggested itself was to mix a certain proportion of charcoal with the earth in which different plants grew, and to increase its quantity according as the advantage of the method was perceived. An addition of ⅙ charcoal, for example, to vegetable mould, appeared to answer excellently for the *Gesneria* and *Gloxinia*, and also for the tropical *Aroideæ* with tuberous roots. The first two soon excited the attention of connoisseurs, by the great beauty of all their parts and their general appearance. They surpassed very quickly those cultivated in the common way, both in the thickness of their stems and dark colour of their leaves; their blossoms were beautiful, and their vegetation lasted much longer than usual, so much so, that in the middle of November, when other plants of the same kinds were dead, these were quite fresh and partly in bloom. *Aroideæ* took root very rapidly, and their leaves surpassed much in size the leaves of those not so treated; the species which are reared as ornamental plants on account of the beautiful colouring of their leaves, (I mean such as the *Caladium bicolor, Pictum, Pœcile,* &c.,) were particularly remarked for the liveliness of their tints; and it happened here also, that the period of their vegetation was unusually long. A cactus planted in a mixture of equal parts of charcoal and earth throve progressively, and attained double of its former size in the space of a few weeks. The use of the charcoal was very advantageous with several of the *Bromeliaceæ*, and *Lilaceæ*, with the *Citrus*, and *Begonia* also, and even with the *Palmæ*. The same advantage was found in the case of almost all those plants for which sand is used, in order to keep the earth porous, when charcoal was mixed with the soil instead of sand; the vegetation was always rendered stronger and more vigorous.

"At the same time that these experiments were performed with mixtures of charcoal with different soils, the charcoal was also used free from any addition, and in this case the best results were obtained. Cuts of plants from different genera took root in it well and quickly; I mention here only the *Euphorbia fastuosa* and *fulgens* which took root in ten days, *Pandanus utilis* in three months, *P. amaryllifolius, Chamædorea elatior* in four weeks, *Piper nigrum, Begonia, Ficus, Cecropia, Chiococca, Buddleya, Hakea, Phyllanthus, Capparis, Laurus, Stifftia, Jacquinia, Mimosa, Cactus,* in from eight to ten days, and several others amounting to forty species, including *Ilex*, and many others. Leaves, and pieces of leaves, and even *pedunculi*, or petioles, took root and in part budded in pure charcoal. Amongst others we may mention the *foliola* of several of the *Cycadeæ* as having taken root, as also did parts of the leaves of the *Begonia Telfairiæ*, and *Jacaranda brasiliensis;* leaves of the *Euphorbia fastuosa, Oxalis Barrilieri, Ficus, Cyclamen, Polyanthes, Mesembryanthemum;* also the delicate leaves of the *Lophospermum* and *Martynia*, pieces of a leaf of the *Agave americana;* tufts of *Pinus*, &c.; and all without the aid of a previously formed bud.

"Pure charcoal acts excellently as a means of curing unhealthy plants. A *Dorianthes excelsa*, for example, which had been drooping for three years, was rendered completely healthy in a very short time by this means. An orange-tree which had the very common disease in which the leaves become yellow, acquired within four weeks its healthy green colour, when the upper surface of the earth was removed from the pot in which it was contained, and a ring of charcoal of an inch in thickness strewed in its place around the periphery of the pot. The same was the case with the *Gardenia*.

"I should be led too far were I to state all the results of the experiments which I have made with charcoal. The object of this paper is merely to show the general effect exercised by this substance on vegetation; but the reader who takes particular interest in the subject will find more extensive observations in the '*Allgemeine Deutsche Gartenzeitung*' of Otto and Dietrich, in Berlin; or Loudon's *Gardener's Magazine* for March, 1841.

"The charcoal employed in these experiments was the dust-like powder of charcoal from firs and pines, such as is used in the forges of blacksmiths, and may be easily procured in any quantity. It was found to have most effect when allowed to lie during the winter exposed to the action of the air. In order to ascertain the effects of different kinds of charcoal, experiments were also made upon that obtained from the hard woods and peat, and also upon animal charcoal, although I foresaw the probability that none of them would answer so well as that of pine-wood, both on account of its porosity and the ease with which it is decomposed.*

"It is superfluous to remark, that in treating plants in the manner here described, they must be plentifully supplied with water, since the air having such free access penetrates and dries the roots, so that unless this precaution is taken, the failure of all such experiments is unavoidable.

"The action of charcoal consists primarily in its preserving the parts of the plants with which it is in contact—whether they be roots, branches, leaves, or pieces of leaves—unchanged in their vital power for a long space of time, so that the plant obtains time to develope the organs which are necessary for its further support and propagation. There can scarcely be a doubt also that the charcoal undergoes decomposition; for after being used five to six years it becomes a coaly earth; and if this is the case, it must yield carbon, or carbonic oxide, abundantly to the plants growing in it, and thus afford the principal substance necessary for the nutrition of vegetables.† In what other manner indeed can we explain the deep green colour and great luxuriance of the leaves and every part of the plants, which can be obtained in no other kind of soil, according to the opinion of men well qualified to judge? It exercises likewise a favourable influence by decomposing and absorbing the matters excreted by the roots, so as to keep the soil free from the putrefying substances which are often the cause of the death of the *spongiolæ*. Its porosity, as well as the power which it possesses of absorbing water with rapidity, and, after its saturation, of allowing all other water to sink through it, are causes also of its favourable effects. These experiments show what a close affinity the component parts of charcoal have to all plants, for every experiment was crowned with success, although plants belonging to a great many different families were subjected to trial." (*Buchner's Repertorium*, ii. *Reihe*, xix. *Bd. S.* 38.)

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* See page 27.

* M. Lukas has recently repeated these experiments, and found that the animal charcoal obtained by the calcination of bones possesses a decided advantage over all other kinds of charcoal, which he subjected to experiment.—*Liebig's Annalen, Band* xxxix. *Heft* I. *S.* 127.

† As some misconception has arisen regarding this explanation of the action of charcoal upon vegetation, and an idea propagated that the introduction of these opinions into this work incorporated them with those of Liebig, it is necessary to state that they are merely inserted here as part of the papers of M. Lukas. The true explanation has been given in a former part of the work, viz., that charcoal possesses the power of absorbing carbonic acid and ammonia from the atmosphere, which serve for the nourishment of plants.—Ed.

ON A MODE OF MANURING VINES.

The observations contained in the following pages should be extensively known, because they furnish a remarkable proof of the principles which have been stated in the preceding part of the work, both as to the manner in which manure acts, and on the origin of the carbon and nitrogen of plants.

They prove that a vineyard may be retained in fertility without the application of animal matters, when the leaves and branches pruned from the vines are cut into small pieces and used as manure. According to the first of the following statements, both of which merit complete confidence, the perfect fruitfulness of a vineyard has been maintained in this manner for eight years, and according to the second statement for ten years.

Now, during this long period, no carbon was conveyed to the soil, for that contained in the pruned branches was the produce of the plant itself, so that the vines were placed exactly in the same condition as trees in a forest which received no manure. Under ordinary circumstances a manure containing potash must be used, otherwise the fertility of the soil will decrease. This is done in all wine-countries, so that alkalies to a very considerable amount must be extracted from the soil.

When, however, the method of manuring now to be described is adopted, the quantity of alkalies exported in the wine does not exceed that which the progressive disintegration of the soil every year renders capable of being absorbed by the plants. On the Rhine 1 litre of wine is calculated as the yearly produce of a square metre of land (10·8 square feet English.) Now if we suppose that the wine is three-fourths saturated with cream of tartar, a proportion much above the truth, then we remove from every square metre of land with the wine only 1·8 gramme of potash. 1000 grammes (1 litre) of champagne yield only 1.54, and the same quantity of Wachenheimer 1·72 of a residue which after being heated to redness is found to consist of carbonates.

One vine-stock, on an average, grows on every square metre of land, and 1000 parts of the pruned branches contain 56 to 60 parts of carbonate, or 38 to 40 parts of pure potash. Hence it is evident that 45 grammes, or 1 ounce, of these branches contain as much potash as 1000 grammes (1 litre) of wine. But from ten to twenty times this quantity of branches are yearly taken from the above extent of surface.

In the vicinity of Johannisberg, Rudesheim, and Budesheim, new vines are not planted after the rooting out of the old stocks, until the land has lain for five or six years in barley and esparcet, or lucerne; in the sixth year the young stocks are planted, but not manured till the ninth.

ON THE MANURING OF THE SOIL IN VINEYARDS.*

"In reference to an article in your paper, No. 7, 1838, and No. 29, 1839, I cannot omit the opportunity of again calling the public attention to the fact, that nothing more is necessary for the manure of a vineyard than the branches which are cut from the vines themselves.

"My vineyard has been manured in this way for eight years, without receiving any other kind of manure, and yet more beautiful and richly laden vines could scarcely be pointed out. I formerly followed the method usually practised in this district, and was obliged in consequence to purchase manure to a large amount. This is now entirely saved, and my land is in excellent condition.

"When I see the fatiguing labour used in the manuring of vineyards—horses and men toiling up the mountains with unnecessary materials—I feel inclined to say to all, Come to my vineyard and see how a bountiful Creator has provided that vines shall manure themselves, like the trees in a forest, and even better than they! The foliage falls from trees in a forest, only when they are withered, and they lie for years before they decay; but the branches are pruned from the vine in the end of July or beginning of August whilst still fresh and moist. If they are then cut into small pieces and mixed with the earth, they undergo putrefaction so completely, that, as I have learned by experience, at the end of four weeks not the smallest trace of them can be found."

"Remarks of the Editor.—We find the following notices of the same fact in Henderson's '*Geschichte der Weine der alten und neuen Zeit*:'—

"'The best manure for vines is the branches pruned from the vines themselves, cut into small pieces, and immediately mixed with the soil.'

"These branches were used as manure long since in the Bergstrasse. M. Frauenfelder says:†

"'I remember that twenty years ago, a man called Peter Müller had a vineyard here which he manured with the branches pruned from the vines, and continued this practice for thirty years. His way of applying them was to hoe them into the soil after having cut them into small pieces.

"'His vineyard was always in a thriving condition; so much so indeed, that the peasants here speak of it to this day, wondering that old Müller had so good a vineyard, and yet used no manure.'

"Lastly, Wilhelm Ruf of Schriesheim writes:

"'For the last ten years I have been unable to place dung on my vineyard, because I am poor and can buy none. But I was very unwilling to allow my vines to decay, as they are my only source of support in my old age; and I often walked very anxiously amongst them, without knowing what I should do. At last my necessities became greater, which made me more attentive, so that I remarked that the grass was longer on some spots where the branches of the vine fell than on those on which there were none. So I thought upon the matter, and then said to myself: If these branches can make the grass large, strong, and green, they must also be able to make my plants grow better, and become strong and green. I dug therefore my vineyard as deep as if I would put dung into it, and cut the branches into pieces, placing them in the holes and covering them with earth. In a year I had the very great satisfaction to see my barren vineyard become quite beautiful. This plan I continued every year, and now my vines grow splendidly, and remain the whole summer green, even in the greatest heat.

"'All my neighbours wonder very much how my vineyard is so rich, and that I obtain so many grapes from it, and yet they all know that I have put no dung upon it for ten years.'"

PART II.

OF THE CHEMICAL PROCESSES OF FERMENTATION, DECAY AND PUTREFACTION.

CHAPTER I.

CHEMICAL TRANSFORMATIONS.

Woody fibre, sugar, gum, and all such organic compounds, suffer certain changes when in contact with other bodies, that is, they suffer *decomposition*.

There are two distinct modes in which these decompositions take place in organic chemistry.

When a substance composed of two compound bodies, crystallized oxalic acid for example, is brought in contact with concentrated sulphuric acid, a complete decomposition is effected upon the application of a gentle heat. Now crystallized oxalic acid is a combination of water with the anhydrous acid; but concentrated sulphuric acid possesses a much greater affinity for water than oxalic acid, so that it attracts all the water of crystallization from that substance. In consequence of this abstraction of the water, anhydrous oxalic acid is set free; but as this acid cannot exist in a free state, a division of its constituents necessarily ensues, by which carbonic acid and carbonic oxide are produced, and evolved in the gaseous form in equal volumes. In this example, the decomposition is the consequence of the removal of two constituents (the elements of water,) which unite with the sulphuric acid, and its cause is the superior affinity of the acting body (the sulphuric acid) for water. In consequence of the removal of the component parts of water, the remaining elements enter into a new form; in place of oxalic acid, we have its elements in the form of carbonic acid and carbonic oxide.

This form of decomposition, in which the change is effected by the agency of a body which unites with one or more of the constituents of a compound, is quite analogous to the decomposition of inorganic substances. When we bring sulphuric acid and nitrate of potash together, nitric acid is separated in consequence of the affinity of sulphuric acid for potash; in consequence, therefore, of the formation of a new compound (sulphate of potash.)

In the second form of these decompositions, the chemical affinity of the acting body causes the component parts of the body which is decomposed to combine so as to form new compounds, of which either both, or only one, combine with the acting body. Let us take dry wood, for example, and moisten it with sulphuric acid; after a short time the wood is carbonised, while the sulphuric acid remains unchanged, with the exception of its being united with more water than it possessed before. Now this water did not exist as such in the wood, although its elements, oxygen and hydrogen, were present; but by the chemical attraction of sulphuric acid for water, they were in a certain measure compelled to unite in this form; and in consequence of this, the carbon of wood was separated as charcoal.

Hydrocyanic acid, and *water*, in contact with hydrochloric acid, are mutually decomposed. The nitrogen of the hydrocyanic acid, and a certain quantity of the hydrogen of the water, unite together and form *ammonia;* whilst the carbon and hydrogen of the hydrocyanic acid combine with the oxygen of the water, and form *formic acid.* The ammonia combines with the muriatic acid. Here the contact of muriatic acid with water and hydrocyanic acid causes a disturbance in the attraction of the elements of both compounds, in consequence of which they arrange themselves into new combinations, one of which—ammonia—possesses the power of uniting with the acting body.

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* Slightly abridged from an article by M. Krebs of Seeheim, in the "Zeitschrift für die landwirthschaftlichen Vereine des Grosherzogthums Hessen." No. 28, July 9, 1840.

† Badisches landwirthschaftliches Wochenblatt, v. 1834, S. 52 and 79.

Inorganic chemistry can present instances analogous to this class of decomposition also; but there are forms of organic chemical decomposition of a very different kind, in which none of the component parts of the matter which suffers decomposition enter into combination with the body which determines the decomposition. In cases of this kind a disturbance is produced in the mutual attraction of the elements of a compound, and they in consequence arrange themselves into one or several new combinations, which are incapable of suffering further change under the same conditions.

When, by means of the chemical affinity of a second body, by the influence of heat, or through any other causes, the composition of an organic compound is made to undergo such a change, that its elements form two or more new compounds, this manner of decomposition is called a chemical *transformation* or *metamorphosis*. It is an essential character of chemical transformations, that none of the elements of the body decomposed are singly set at liberty.

The changes, which are designated by the terms *fermentation, decay,* and *putrefaction*, are chemical transformations effected by an agency which has hitherto escaped attention, but the existence of which will be proved in the following pages.

CHAPTER II

ON THE CAUSES WHICH EFFECT FERMENTATION, DECAY,* AND PUTREFACTION.

ATTENTION has been recently directed to the fact, that a body in the act of combination or decomposition exercises an influence upon any other body with which it may be in contact. Platinum, for example, does not decompose nitric acid; it may be boiled with this acid without being oxidized by it, even when in a state of such fine division, that it no longer reflects light (black spongy platinum.) But an alloy of silver and platinum dissolves with great ease in nitric acid; the oxidation which the silver suffers causes the platinum to submit to the same change; or, in other words, the latter body, from its contact with the oxidizing silver, acquires the property of decomposing nitric acid.

Copper does not decompose water, even when boiled in dilute sulphuric acid; but an alloy of copper, zinc, and nickel, dissolves easily in this acid with evolution of hydrogen gas.

Tin decomposes nitric acid with great facility, but water with difficulty; and yet, when tin is dissolved in nitric acid, hydrogen is evolved at the same time, from a decomposition of the water contained in the acid, and ammonia is formed in addition to oxide of tin.

In the examples here given the only combination or decomposition which can be explained by chemical affinity is the last. In the other cases, electrical action ought to have retarded or prevented the oxidation of the platinum or copper while they were in contact with silver or zinc, but, as experience shows, the influence of the opposite electrical conditions is more than counterbalanced by chemical actions.

The same phenomena are seen in a less dubious form in compounds, the elements of which are held together only by a feeble affinity. It is well known that there are chemical compounds of so unstable a nature, that changes in temperature and electrical condition, or even simple mechanical friction, or contact with bodies of apparently totally indifferent natures, cause such a disturbance in the attraction of their constituents, that the latter enter into new forms, without any of them combining with the acting body. These compounds appear to stand but just within the limits of chemical combination, and agents exercise a powerful influence over them, which are completely devoid of action on compounds of a stronger affinity. Thus, by a slight increase of temperature, the elements of hypochlorous acid separate from one another with evolution of heat and light; chloride of nitrogen explodes by contact with many bodies, which combine neither with chlorine nor nitrogen at common temperatures; and the contact of any solid substance is sufficient to cause the explosion of iodide of nitrogen, or fulminating silver.

It has never been supposed that the causes of the decomposition of these bodies should be ascribed to a peculiar power, different from that which regulates chemical affinity, a power which mere contact with the down of a feather is sufficient to set in activity, and which, once in action, gives rise to the decomposition. These substances have always been viewed as chemical compounds of a very unstable nature, in which the component parts are in a state of such tension, that the least disturbance overcomes their chemical affinity. They exist only by the *vis inertiæ*, and any shock or movement is sufficient to destroy the attraction of their component parts, and consequently their existence in their definite form.

Peroxide of hydrogen belongs to this class of bodies; it is decomposed by all substances capable of attracting oxygen from it, and even by contact with many bodies, such as platinum or silver, which do not enter into combination with any of its constituents. In this respect, its decomposition depends evidently upon the same causes which effect that of iodide of nitrogen, or fulminating silver. Yet it is singular that the cause of the sudden separation of the component parts of peroxide of hydrogen has been viewed as different from those of common decomposition, and has been ascribed to a new power termed the ***catalytic force***. Now, it has not been considered, that the presence of the platinum and silver serves here only to accelerate the decomposition; for without the contact of these metals, the peroxide of hydrogen decomposes spontaneously, although very slowly. The sudden separation of the constituents of peroxide of hydrogen differs from the decomposition of gaseous hypochlorous acid, or solid iodide of nitrogen, only in so far as the decomposition takes place in a liquid.

A remarkable action of peroxide of hydrogen has attracted much attention, because it differs from ordinary chemical phenomena. This is the reduction which certain oxides suffer by contact with this substance, on the instant at which the oxygen separates from the water. The oxides thus easily reduced, are those of which the whole, or part at least, of their oxygen is retained merely by a feeble affinity, such as the oxides of silver and of gold, and peroxide of lead.

Now, other oxides which are very stable in composition, effect the decomposition of peroxide of hydrogen, without experiencing the smallest change; but when oxide of silver is employed to effect the decomposition, all the oxygen of silver is carried away with that evolved from the peroxide of hydrogen, and as a result of the decomposition, water and metallic silver remain. When peroxide of lead is used for the same purpose, half its oxygen escapes as a gas. Peroxide of manganese may in the same manner be reduced to the protoxide, and oxygen set at liberty, if an acid is at the same time present, which will exercise an affinity for the protoxide and convert it into a soluble salt. If, for example, we add to peroxide of hydrogen sulphuric acid, and then peroxide of manganese in the state of fine powder, much more oxygen is evolved than the compound of oxygen and hydrogen could yield; and if we examine the solution which remains, we find a salt of the protoxide of manganese, so that half of the oxygen has been evolved from the peroxide of that metal.

A similar phenomenon occurs, when carbonate of silver is treated with several organic acids. Pyruvic acid, for example, combines readily with pure oxide of silver, and forms a salt of sparing solubility in water. But when this acid is brought in contact with carbonate of silver, the oxygen of part of the oxide escapes with the carbonic acid, and metallic silver remains in the state of a black powder. (Berzelius.)

Now no other explanation of these phenomena can be given, than that a body in the act of combination or decomposition enables another body, with which it is in contact, to enter into the same state. It is evident that the active state of the atoms of one body has an influence upon the atoms of a body in contact with it; and if these atoms are capable of the same change as the former, they likewise undergo that change; and combinations and decompositions are the consequence. But when the atoms of the second body are not capable of such an action, any further disposition to change ceases from the moment at which the atoms of the first body assume the state of rest, that is when the changes or transformations of this body are quite completed.

This influence exerted by one compound upon the other, is exactly similar to that which a body in the act of combustion exercises upon a combustible body in its vicinity; with this difference only, that the causes which determine the participation and duration of these conditions are different. For the cause, in the case of the combustible body, is heat, which is generated every moment anew; whilst in the phenomena of decomposition and combination, which we are considering at present, the cause is a body in the state of chemical action, which exerts the decomposing influence only so long as this action continues.

Numerous facts show that motion alone exercises a considerable influence on chemical forces. Thus, the power of cohesion does not act in many saline solutions, even when they are fully saturated with salts, if they are permitted to cool while at rest. In such a case, the salt dissolved in a liquid does not crystallize; but when a grain of sand is thrown into the solution, or when it receives the slightest movement, the whole liquid becomes suddenly solid while heat is evolved. The same phenomenon happens with water, for this liquid may be cooled much under 32° F. (0° C.,) if kept completely undisturbed, but solidifies in a moment when put in motion.

The atoms of a body must in fact be set in motion before they can overcome the *vis inertiæ* so as to arrange themselves into certain forms. A dilute solution of a salt of potash mixed with tartaric acid yields no precipitate whilst at rest; but if motion is communicated to the solution by agitating it briskly, solid crystals of cream of tartar are deposited. A solution of a salt of magnesia also, which is not rendered turbid by the addition of phosphate of ammonia, deposits the phosphate of magnesia and ammonia on those parts of the vessel touched with the rod employed in stirring.

In the processes of combination and decomposition under consideration, motion, by overcoming the *vis inertiæ*, gives rise immediately to another arrangement of the atoms of a body, that is, to the production of a compound which did not before exist in it. Of course these atoms must previously possess the power of arranging themselves

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* An essential distinction is drawn in the following part of the work, between *decay* and *putrefaction* (*Verwesung und Faulniss*,) and they are shown to depend on different causes; but as the word *decay* is not generally applied to a distinct species of decomposition, and does not indicate its true nature, I shall in future, at the suggestion of the author, employ the term *eremacausis*, the meaning of which has been already explained.—ED.

in a certain order, otherwise both friction and motion would be without the smallest influence.

The simple permanence in position of the atoms of a body, is the reason that so many compounds appear to present themselves, in conditions, and with properties, different from those which they possess, when they obey the natural attractions of their atoms. Thus sugar and glass, when melted and cooled rapidly, are transparent, of a conchoidal fracture, and elastic and flexible to a certain degree. But the former becomes dull and opaque on keeping, and exhibits crystalline faces by cleavage, which belong to crystallized sugar. Glass assumes also the same condition, when kept soft by heat for a long period; it becomes white, opaque, and so hard as to strike fire with steel. Now, in both these bodies, the compound molecules evidently have different positions in the two forms. In the first form their attraction did not act in the direction in which their power of cohesion was strongest. It is known also, that when sulphur is melted and cooled rapidly by throwing it into cold water, it remains transparent, elastic, and so soft that it may be drawn out into long threads; but that after a few hours or days, it becomes again hard and crystalline.

The remarkable fact here is, that the amorphous sugar or sulphur returns again into the crystalline condition, without any assistance from an exterior cause; a fact which shows that their molecules have assumed another position, and that they possess, therefore, a certain degree of mobility, even in the condition of a solid. A very rapid transposition or transformation of this kind is seen in arragonite, a mineral which possesses exactly the same composition as calcareous spar, but of which the hardness and crystalline form prove that its molecules are arranged in a different manner. When a crystal of arragonite is heated, an interior motion of its molecules is caused by the expansion; the permanence of their arrangement is destroyed; and the crystal splinters with much violence, and falls into a heap of small crystals of calcareous spar.

It is impossible for us to be deceived regarding the causes of these changes. They are owing to a disturbance of the state of the equilibrium, in consequence of which the particles of the body put in motion obey other affinities or their own natural attractions.

But if it is true, as we have just shown it to be, that mechanical motion is sufficient to cause a change of condition in many bodies, it cannot be doubted that a body in the act of combination or decomposition is capable of imparting the same condition of motion or activity in which its atoms are to certain other bodies: or in other words, to enable other bodies with which it is in contact to enter into combinations, or suffer decompositions.

The reality of this influence has been already sufficiently proved by the facts derived from inorganic chemistry, but it is of much more frequent occurrence in the relations of organic matter, and causes very striking and wonderful phenomena.

By the terms *fermentation, putrefaction,* and *eremacausis,* are meant those changes in form and properties which compound organic substances undergo when separated from the organism, and exposed to the influence of water and a certain temperature. Fermentation and putrefaction are examples of that kind of decomposition, which we have named transformations: the elements of the bodies capable of undergoing these changes arrange themselves into new combinations, in which the constituents of water generally take a part.

Eremacausis (or decay) differs from fermentation and putrefaction, inasmuch as it cannot take place without the access of air, the oxygen of which is absorbed by the decaying bodies. Hence it is a process of slow combustion, in which heat is uniformly evolved, and occasionally even light. In the processes of decomposition termed fermentation and putrefaction, gaseous products are very frequently formed, which are either inodorous, or possess a very offensive smell.

The transformations of those matters which evolve gaseous products without odour are now, by pretty general consent, designated by the term *fermentation;* whilst to the spontaneous decomposition of bodies which emit gases of a disagreeable smell, the term *putrefaction* is applied. But the smell is of course no distinctive character of the nature of the decomposition, for both fermentation and putrefaction are processes of decomposition of a similar kind, the one of substances destitute of nitrogen, the other of substances which contain it.

It has also been customary to distinguish from fermentation and putrefaction a particular class of transformations, viz., those in which conversions and transpositions are effected without the evolution of gaseous products. But the conditions under which the products of the decomposition present themselves are purely accidental; there is therefore no reason for the distinction just mentioned.

CHAPTER III.

FERMENTATION AND PUTREFACTION.

Several bodies appear to enter spontaneously into the states of fermentation and putrefaction, particularly such as contain nitrogen or azotised substances. Now, it is very remarkable, that very small quantities of these substances, in a state of fermentation or putrefaction, possess the power of causing unlimited quantities of similar matters to pass into the same state. Thus, a

small quantity of the juice of grapes in the act of fermentation, added to a large quantity of the same fluid, which does not ferment, induces the state of fermentation in the whole mass. So likewise the most minute portion of milk, paste, juice of the beet-root, flesh, or blood, in the state of putrefaction, causes fresh milk, paste, juice of the beet-root, flesh or blood, to pass into the same condition when in contact with them.

These changes evidently differ from the class of common decompositions which are effected by chemical affinity; they are chemical actions, conversions, or decompositions, excited by contact with bodies already in the same condition. In order to form a clear idea of these processes, analogous and less complicated phenomena must previously be studied.

The compound nature of the molecules of an organic body, and the phenomena presented by them when in relation with other matters, point out the true cause of these transformations. Evidence is afforded even by simple bodies, that in the formation of combinations, the force with which the combining elements adhere to one another is inversely proportional to the number of simple atoms in the compound molecule. Thus, protoxide of manganese by absorption of oxygen is converted into the sesquioxide, the peroxide, manganic and hypermanganic acids, the number of atoms of oxygen being augmented by $\frac{1}{2}$, by 1, by 2, and by 5. But all the oxygen contained in these compounds, beyond that which belongs to the protoxide, is bound to the manganese by a much more feeble affinity; a red heat causes an evolution of oxygen from the peroxide, and the manganic and hypermanganic acids cannot be separated from their bases without undergoing immediate decomposition.

There are many facts which prove, that the most simple inorganic compounds are also the most stable, and undergo decomposition with the greatest difficulty, whilst those which are of a complex composition yield easily to changes and decompositions. The cause of this evidently is, that in proportion to the number of atoms which enter into a compound, the directions in which their attractions act will be more numerous.

Whatever ideas we may entertain regarding the infinite divisibility of matter in general, the existence of chemical proportions removes every doubt respecting the presence of certain limited groups or masses of matter which we have not the power of dividing. The particles of matter called equivalents in chemistry are not infinitely small, for they possess a weight, and are capable of arranging themselves in the most various ways, and of thus forming innumerable compound atoms. The properties of these compound atoms differ in organic nature, not only according to the form, but also in many instances according to the direction and place, which the simple atoms take in the compound molecules.

When we compare the composition of organic compounds with inorganic, we are quite amazed at the existence of combinations, in one single molecule of which, ninety or several hundred atoms or equivalents are united. Thus, the compound atom of an organic acid of very simple composition, acetic acid for example, contains twelve equivalents of simple elements; one atom of kinovic acid contains 33, 1 of sugar 36, 1 of amygdalin 90, and 1 of stearic acid 138 equivalents. The component parts of animal bodies are infinitely more complex even than these.

Inorganic compounds differ from organic in as great a degree in their other characters as in their simplicity of constitution. Thus, the decomposition of a compound atom of sulphate of potash is aided by numerous causes, such as the power of cohesion, or the capability of its constituents to form solid, insoluble, or at certain temperatures volatile compounds with the body brought into contact with it, and nevertheless a vast number of other substances produce in it not the slightest change. Now, in the decomposition of a complex organic atom, there is nothing similar to this.

The empirical formula of sulphate of potash is SKO^4. It contains only 1 eq. of sulphur, and 1 eq. of potassium. We may suppose the oxygen to be differently distributed in the compound, and by a decomposition we may remove a part or all of it, or replace one of the constituents of the compound by another substance. But we cannot produce a different arrangement of the atoms, because they are already disposed in the simplest form in which it is possible for them to combine. Now, let us compare the composition of sugar of grapes with the above: here 12 eq. of carbon, 12 eq. of hydrogen, and 12 eq. of oxygen, are united together, and we know that they are capable of combining with each other in the most various ways. From the formula of sugar we might consider it either as a hydrate of carbon, wood, starch, or sugar of milk, or farther, as a compound of ether with alchohol or of formic acid with sachulmin.[*] Indeed we may calculate almost all the known organic compounds destitute of nitrogen from sugar, by simply adding the elements of water, or by replacing any one of its elementary constituents by a different substance. The elements necessary to form these compounds are therefore contained in the sugar, and they must also possess the power of forming numerous combinations amongst themselves by their mutual attractions.

Now, when we examine what changes sugar undergoes when brought into contact with other bodies which exercise a marked influence upon it, we find, that these changes are not confined to any narrow limits, like those of inorganic bodies, but are in fact unlimited.

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[*] The black precipitate obtained by the action of hydrochloric acid on sugar.

The elements of sugar yield to every attraction, and to each in a peculiar manner. In inorganic compounds, an acid acts upon a particular constituent of the body, which it decomposes, by virtue of its affinity for that constituent, and never resigns its proper chemical character, in whatever form it may be applied. But when it acts upon sugar, and induces great changes in that compound, it does this not by any superior affinity for a base existing in the sugar, but by disturbing the equilibrium in the mutual attraction of the elements of the sugar amongst themselves. Muriatic and sulphuric acids, which differ so much from one another both in characters and composition, act in the same manner upon sugar. But the action of both varies according to the state in which they are; thus they act in one way when dilute, in another when concentrated, and even differences in their temperature cause a change in their action. Thus sulphuric acid of a moderate degree of concentration converts sugar into a black carbonaceous matter, forming at the same time acetic and formic acids. But when the acid is more diluted, the sugar is converted into two brown substances, both of them containing carbon and the elements of water. Again, when sugar is subjected to the action of alkalies, a whole series of different new products are obtained; while oxidizing agents, such as nitric acid, produce from it carbonic acid, acetic acid, oxalic acid, formic acid, and many other products which have not yet been examined.

If from the facts here stated we estimate the power with which the elements of sugar are united together, and judge of the force of their attraction by the resistance which they offer to the action of bodies brought into contact with them, we must regard the atom of sugar as belonging to that class of compound atoms, which exist only by the *vis inertiæ* of their elements. Its elements seem merely to retain passively the position and condition in which they had been placed, for we do not observe that they resist a change of this condition by their own mutual attraction, as is the case with sulphate of potash.

Now it is only such combinations as sugar, combinations therefore which possess a very complex molecule, which are capable of undergoing the decompositions named fermentation and putrefaction.

We have seen that metals acquire a power which they do not of themselves possess, namely, that of decomposing water and nitric acid, by simple contact with other metals in the act of chemical combination. We have also seen, that peroxide of hydrogen and the persulphuret of the same element, in the act of decomposition, cause other compounds of a similar kind, but of which the elements are much more strongly combined, to undergo the same decomposition, although they exert no chemical affinity or attraction for them or their constituents. The cause which produces these phenomena will be also recognised, by attentive observation, in those matters which excite fermentation or putrefaction. All bodies in the act of combination or decomposition have the property of inducing those processes; or, in other words, of causing a disturbance of the statical equilibrium in the attractions of the elements of complex organic molecules, in consequence of which those elements group themselves anew, according to their special affinities.

The proofs of the existence of this cause of action can be easily produced; they are found in the characters of the bodies which effect fermentation and putrefaction, and in the regularity with which the distribution of the elements takes place in the subsequent transformations. This regularity depends exclusively on the unequal affinity which they possess for each other in an isolated condition. The action of water on wood, charcoal, and cyanogen, the simplest of the compounds of nitrogen, suffices to illustrate the whole of the transformations of organic bodies; of those in which nitrogen is a constituent, and of those in which it is absent.

CHAPTER IV.

ON THE TRANSFORMATION OF BODIES WHICH DO NOT CONTAIN NITROGEN AS A CONSTITUENT, AND OF THOSE IN WHICH IT IS PRESENT.

When oxygen and hydrogen combined in equal equivalents, as in steam, are conducted over charcoal, heated to the temperature at which it possesses the power to enter into combination with one of these elements, a decomposition of steam ensues. An oxide of carbon (either carbonic oxide or carbonic acid) is under all circumstances formed, while the hydrogen of the water is liberated, or, if the temperature be sufficient, unites with the carbon, forming carburetted hydrogen. Accordingly, the carbon is shared between the elements of the water, the oxygen and hydrogen. Now a participation of this kind, but even more complete, is observed in every transformation, whatever be the nature of the causes by which it is effected.

Acetic and meconic* acids suffer a true transformation under the influence of heat, that is, their component elements are disunited, and form new compounds without any of them being singly disengaged. Acetic acid is converted into acetone and carbonic acid ($C_4 H_3 O_3 = C_3 H_3 O + CO_2$,) and meconic acid into carbonic acid and komenic acid; whilst by the influence of a higher temperature, the latter is further decomposed into pyromeconic acid and carbonic acid.

Now in these cases the carbon of the bodies decomposed is shared between the oxygen and the hydrogen; part of it unites with the oxygen and forms carbonic acid, whilst the other portion enters into combination with the hydrogen, and an oxide of a carbo-hydrogen is formed, in which all the hydrogen is contained.

In a similar manner, when alcohol is exposed to a gentle red heat, its carbon is shared between the elements of the water—an oxide of a carbo-hydrogen which contains all the oxygen, and some gaseous compounds of carbon and hydrogen being produced.

It is evident that during transformations caused by heat, no foreign affinities can be in play, so that the new compounds must result merely from the elements arranging themselves, according to the degree of their mutual affinities, into new combinations which are constant and unchangeable in the conditions under which they were originally formed, but undergo changes when these conditions become different. If we compare the products of two bodies, similar in composition but different in properties, which are subjected to transformations by two different causes, we find that the manner in which the atoms are transposed, is absolutely the same in both.

In the transformation of wood in marshy soils, by what we call putrefaction, its carbon is shared between the oxygen and hydrogen of its own substance, and of the water—carburetted hydrogen is consequently evolved, as well as carbonic acid, both of which compounds have an analogous composition (CH_2, CO_2.)

Thus also in that transformation of sugar, which is called fermentation, its elements are divided into two portions; the one, carbonic acid, which contains $\frac{2}{3}$ of the oxygen of sugar; and the other, alcohol, which contains all its hydrogen.

In the transformation of acetic acid produced by a red heat, carbonic acid, which contains 2-3 of the oxygen of the acetic acid, is formed, and acetone, which contains all its hydrogen.

It is evident from these facts, that the elements of a complex compound are left to their special attractions whenever their equilibrium is disturbed, from whatever cause this disturbance may proceed. It appears also, that the subsequent distribution of the elements, so as to form new combinations, always takes place in the same way, with this difference only, that the nature of the products formed is dependent upon the number of atoms of the elements which enter into action; or, in other words, that the products differ *ad infinitum*, according to the composition of the original substance

ON THE TRANSFORMATION OF BODIES CONTAINING NITROGEN.

When those substances are examined which are most prone to fermentation and putrefaction, it is found that they are all, without exception, bodies which contain nitrogen. In many of these compounds, a transposition of their elements occurs spontaneously as soon as they cease to form part of a living organism; that is, when they are drawn out of the sphere of attraction in which alone they are able to exist.

There are, indeed, bodies destitute of nitrogen, which possess a certain degree of stability only when in combination, but which are unknown in an isolated condition, because their elements, freed from the power by which they were held together, arrange themselves according to their own natural attractions. Hypermanganic, maganic, and hyposulphurous acids, belong to this class of substances, which however are rare.

The case is very different with azotised bodies. It would appear that there is some peculiarity in the nature of nitrogen, which gives its compounds the power to decompose spontaneously with so much facility. Now, nitrogen is known to be the most indifferent of all the elements; it evinces no particular attraction to any one of the simple bodies; and this character it preserves in all its combinations, a character which explains the cause of its easy separation from the matters with which it is united.

It is only when the quantity of nitrogen exceeds a certain limit, that azotised compounds have some degree of permanence, as is the case with melamin, ammelin, &c. Their liability to change is also diminished, when the quantity of nitrogen is very small in proportion to that of the other elements with which it is united, so that their mutual attractions preponderate.

This easy transposition of atoms is best seen in the fulminating silvers, in fulminating mercury, in the iodide or chloride of nitrogen, and in all fulminating compounds.

All other azotised substances acquire the same power of decomposition, when the elements of water are brought into play; and indeed, the greater part of them are not capable of transformation, while this necessary condition to the transposition of their atoms is absent. Even the compounds of nitrogen, which are most liable to change, such as those which are found in animal bodies, do not enter into a state of putrefaction when dry.

The result of the known transformations of azotised substances proves that the water does not merely act as a medium in which motion is permitted to the elements in the act of transposition, but that its influence depends on chemical affinity. When the decomposition of such substances is effected with the assistance of water, their nitrogen is invariably liberated in the form of ammonia. This is a fixed rule without any exceptions, whatever may be the cause which produces the decompositions. All organic compounds containing nitrogen, evolve the whole of that element in the form of ammonia when acted on by alkalies. Acids, and increase of temperature, produce the same effect. It is only when there is a deficiency of water or its elements, that cynogen or other azotised compounds are produced.

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* An acid existing in opium, and named from the Greek for poppy.

From these facts it may be concluded, that ammonia is the most stable compound of nitrogen; and that hydrogen and nitrogen possess a degree of affinity for each other surpassing the attraction of the latter body for any other element.

Already in considering the transformations of substances destitute of nitrogen, we have recognised the great affinity of carbon for oxygen as a powerful cause for effecting the disunion of the elements of a complex organic atom in a definite manner. But carbon is also invariably contained in azotised organic compounds, while the great affinity of nitrogen for hydrogen furnishes a new and powerful cause, facilitating the transposition of their component parts. Thus, in the bodies which do not contain nitrogen we have one element, and in those in which that substance is present, two elements, which mutually share the elements of water. Hence there are two opposite affinities at play, which mutually strengthen each other's actions.

Now we know, that the most powerful attractions may be overcome by the influence of two affinities. Thus, a decomposition of alumina may be effected with the greatest facility, when the affinity of charcoal for oxygen, and of chlorine for aluminium, are both put in action, although neither of these alone has any influence upon it. There is in the nature and constitution of the compounds of nitrogen a kind of tension of their component parts, and a strong disposition to yield to transformations, which effect spontaneously the transposition of their atoms on the instant that water or its elements are brought in contact with them.

The characters of the hydrated cyanic acid, one of the simplest of all the compounds of nitrogen, are perhaps the best adapted to convey a distinct idea of the manner in which the atoms are disposed of in transformations. This acid contains nitrogen, hydrogen, and oxygen, in such proportions, that the addition of a certain quantity of the elements of water is exactly sufficient to cause the oxygen contained in the water and acid to unite with the carbon and form carbonic acid, and the hydrogen of the water to combine with the nitrogen and form ammonia. The most favourable conditions for a complete transformation are, therefore, associated in these bodies, and it is well known, that the disunion takes place on the instant in which the cyanic acid and water are brought into contact, the mixture being converted into carbonic acid and ammonia, with brisk effervescence.

This decomposition may be considered as the type of the transformations of all azotised compounds; it is putrefaction in its simplest and most perfect form, because the new products, the carbonic acid and ammonia are incapable of further transformations.

Putrefaction assumes a totally different and much more complicated form, when the products, which are first formed undergo a further change. In these cases the process consists of several stages, of which it is impossible to determine when one ceases and the other begins.

The transformations of cyanogen, a body composed of carbon and nitrogen, and the simplest of all the compounds of nitrogen, will convey a clear idea of the great variety of products which are produced in such a case: it is the only example of the putrefaction of an azotised body which has been at all accurately studied.

A solution of cyanogen in water becomes turbid after a short time, and deposits a black, or brownish black matter, which is a combination of ammonia with another body, produced by the simple union of cyanogen with water. This substance is insoluble in water, and is thus enabled to resist further change.

A second transformation is effected by the cyanogen being shared between the elements of the water, in consequence of which *cyanic acid* is formed by a certain quantity of the cyanogen combining with the oxygen of the water, while *hydrocyanic acid* is also formed by another portion of the cyanogen uniting with the hydrogen which was liberated.

Cyanogen experiences a third transformation, by which a complete disunion of its elements takes place, these being divided between the constituents of the water. *Oxalic acid* is the one product of this disunion, and *ammonia* the other.

Cyanic acid, the formation of which has been mentioned above, cannot exist in contact with water, being decomposed immediately into carbonic acid and ammonia. The cyanic acid, however, newly formed in the decomposition of cyanogen, escapes this decomposition by entering into combination with the free ammonia, by which *urea* is produced.

The hydrocyanic acid is also decomposed into a brown matter which contains hydrogen and cyanogen, the latter in greater proportion than it does in the gaseous state. Oxalic acid, urea, and carbonic acid, are also formed by its decomposition, and *formic acid* and *ammonia* are produced by the decomposition of its radical.

Thus, a substance into the composition of which only two elements (carbon and nitrogen) enter, yields eight totally different products. Several of these products are formed by the transformation of the original body, its elements being shared between the

constituents of water; others are produced in consequence of a further disunion of those first formed. The urea and carbonate of ammonia are generated by the combination of two of the products, and in their formation the whole of the elements have assisted.

These examples show, that the results of decomposition by fermentation or putrefaction comprehend very different phenomena. The first kind of transformation is, the transposition of the elements of one complex compound, by which new compounds are produced with or without the assistance of the elements of water. In the products newly formed in this manner, either the same proportions of those component parts which were contained in the matter before transformation, are found, or with them, an excess, consisting of the constituents of water which had assisted in promoting the disunion of the elements.

The second kind of transformation consists of the transpositions of the atoms of two or more complex compounds, by which the elements of both arrange themselves mutually into new products, with or without the co-operation of the elements of water. In this kind of transformations, the new products contain the sum of the constituents of all the compounds which had taken a part in the decomposition.

The first of these two modes of decomposition is that designated *fermentation*, the second *putrefaction*; and when these terms are used in the following pages, it will always be to distinguish the two processes above described, which are so different in their results.

CHAPTER V.

FERMENTATION OF SUGAR.

THE peculiar decomposition which sugar suffers may be viewed as a type of all the transformations designated fermentation.*

Thénard obtained from 100 grammes of cane-sugar 0.5262 of absolute alcohol. 100 parts of sugar from the cane yield, therefore, 103.89 parts of carbonic acid and alcohol. The entire carbon in these products is equal to 42 parts, which is exactly the quantity originally contained in the sugar.

The analysis of sugar from the cane, proves that it contains the elements of carbonic acid and alcohol, *minus* 1 atom of water. The alcohol and carbonic acid produced by the fermentation of a certain quantity of sugar, contain together one equivalent of oxygen and one equivalent of hydrogen, the elements, therefore, of one equivalent of water, more than the sugar contained. The excess of weight in the products is thus explained most satisfactorily; it is owing, namely, to the elements of water having taken part in the metamorphosis of the sugar.

It is known that 1 atom of sugar contains 12 equivalents of carbon, both from the proportions in which it unites with bases, and from the composition of saccharic acid the product of its oxidation. Now none of these atoms of carbon are contained in the sugar as carbonic acid, because the whole quantity is obtained as oxalic acid, when sugar is treated with hypermanganate of potash (Gregory;) and as oxalic acid is a lower degree of the oxidation of carbon than carbonic acid, it is impossible to conceive that the lower degree should be produced from the higher, by means of one of the most powerful agents of oxidation which we possess.

It can be also proved, that the hydrogen of the sugar does not exist in it in the form of alcohol, for it is converted into water and a kind of carbonaceous matter, when treated with acids, particularly with such as contain no oxygen; and this manner of decomposition is never suffered by a compound of alcohol.

Sugar contains, therefore, neither alcohol nor carbonic acid, so that these bodies must be produced by a different arrangement of its atoms, and by their union with the elements of water.

In this metamorphosis of sugar, the elements of the yeast, by contact with which its fermentation was effected, take no appreciable part in the transposition of the elements of the sugar; for in the products resulting from the action, we find no component part of this substance.

We may now study the fermentation of a vegetable juice, which contains not only saccharine matter, but also such substances as albumen and gluten. The juices of parsneps, beet-roots, and onions, are well adapted for this purpose. When such a juice is mixed with yeast at common temperatures, it ferments like a solution of sugar. Carbonic acid gas escapes from it with effervescence, and in the liquid, alcohol is found in quantity exactly corresponding to that of the sugar originally contained in the juice. But such a juice undergoes spontaneous decomposition at a temperature of from 95° to 104° (35°—40° C.) Gases possessing an offensive smell are evolved in considerable quantity, and when the liquor is examined after the decomposition is completed, no alcohol can be detected. The sugar has also disappeared, and with it all the azotised compounds which existed in the juice previously to its fermentation. Both were decomposed at the same time; the nitrogen of the azotised compounds remains in the liquid as ammoina, and, in addition to it, there are three new products, formed from the component parts of the juice. One of these is lactic acid, the slightly volatile compound found in the animal organism; the other is the crystalline body which forms the principal constituent of manna; and the third is a mass resembling gum-arabic, which forms a thick viscous solution with water. These three products weigh more than the sugar contained in the juice, even without calculating the weight of the gaseous products. Hence they are not produced from the elements of the sugar alone. None of these three substances could be detected in the juice before fermentation. They must, therefore, have been formed by the interchange of the elements of the sugar with those of the foreign substances also present. It is this mixed transformation of two or more compounds which receives the special name of *putrefaction.*

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* When yeast is made into a thin paste with water, and 1 cubic centimetre of this mixture introduced into a graduated glass receiver filled with mercury, in which are already 19 grammes of a solution of cane sugar, containing 1 gramme of pure solid sugar; it is found after the mixture has been exposed for 24 hours to a temperature of from 20 to 25 C. (68—77 F.,) that a volume of carbonic acid has been formed, which, at 0° C. (32° F.) and an atmospheric pressure indicated by 0.76 metre Bar. would be from 245 to 250 cubic centimetres. But to this quantity we must add 11 cubic centimetres of carbonic acid, with which the 11 grammes of liquid would be saturated, so that in all 255—259 cubic centimetres of carbonic acid are obtained. This volume of carbonic acid corresponds to from 0.503 to 0.5127 grammes by weight.

YEAST OR FERMENT.

When attention is directed to the condition of those substances which possess the power of inducing fermentation and putrefaction in other bodies, evidences are found in their general characters, and in the manner in which they combine, that they all are bodies, the atoms of which are in the act of transposition.

The characters of the remarkable matter which is deposited in an insoluble state during the fermentation of beer, wine, and vegetable juices, may first be studied.

This substance, which has been called *yeast* or *ferment,* from the power which it possesses of causing fermentation in sugar, or saccharine vegetable juices, possesses all the characters of a *compound of nitrogen in the state of putrefaction and eremacausis.*

Like wood in the state of eremacausis, yeast converts the oxygen of the surrounding air into carbonic acid, but it also evolves this gas from its own mass, like bodies in the state of putrefaction. (Colin.) When kept under water, it emits carbonic acid, accompanied by gases of an offensive smell, (Thénard,) and is at last converted into a substance resembling old cheese. (Proust.) But when its own putrefaction is completed, it has no longer the power of inducing fermentation in other bodies. The presence of water is quite necessary for sustaining the properties of ferment, for by simple pressure its power to excite fermentation is much diminished, and is completely destroyed by drying. Its action is arrested also by the temperature of boiling water, by alcohol, common salt, an excess of sugar, oxide of mercury, corrosive sublimate, pyroligneous acid, sulphurous acid, nitrate of silver, volatile oils, and in short by all antiseptic substances.

The insoluble part of the substance called ferment does not cause fermentation. For when the yeast from wine or beer is carefully washed with water, care being taken that it is always covered with this fluid, the residue does not produce fermentation.

The soluble part of ferment likewise does not excite fermentation. An aqueous infusion of yeast may be mixed with a solution of sugar, and preserved in vessels from which the air is excluded, without either experiencing the slightest change. What then, we may ask, is the matter in ferment which excites fermentation, if neither the soluble nor insoluble parts possess the power? This question has been answered by *Colin* in the most satisfactory manner. He has shown that in reality *it is the soluble part.* But before it obtains this power, the decanted infusion must be allowed to cool in contact with the air, and to remain some time exposed to its action. When introduced into a solution of sugar in this state, it produces a brisk fermentation; but without previous exposure to the air, it manifests no such property.

The infusion absorbs oxygen during its exposure to the air, and carbonic acid may be found in it after a short time.

Yeast produces fermentation in consequence of the progressive decomposition which it suffers from the action of air and water.

Now when yeast is made to act on sugar, it is found, that after the transformation of the latter substance into carbonic acid and alcohol is completed, part of the yeast itself has disappeared.

From 20 parts of fresh yeast from beer, and 100 parts of sugar, *Thénard* obtained, after the fermentation was completed, 13·7 parts of an insoluble residue, which diminished to 10 parts when employed in the same way with a fresh portion of sugar. These ten parts were white, possessed of the properties of woody fibre, and had no farther action on sugar.

It is evident, therefore, that during the fermentation of sugar by yeast, both of these substances suffer decomposition at the same time, and disappear in consequence. But if yeast be a body which excites fermentation by being itself in a state of decomposition, all other matters in the same condition should have a similar action upon sugar; and this is in reality the case. Muscle, urine, isinglass, osmazome, albumen, cheese, gliadine, gluten, legumin, and blood, when in a state of putrefaction, have all the power of producing the putrefaction, or fermentation of a solution of sugar. Yeast, which by continued washing has entirely lost the property of inducing fermentation, regains it when its putrefaction has recommenced, in consequence of its being kept in a warm situation for some time.

Yeast and putrefying animal and vegetable matters act as peroxide of hydrogen does on oxide of silver, when they induce bodies with which they are in contact to enter into the same state of decomposition. The disturbance in the attraction of the constituents of the peroxide of hydrogen effects a disturbance in the attraction of the elements of the oxide of silver, the one being decomposed, on account of the decomposition of the other.

Now if we consider the process of the fermentation of pure sugar, in a practical point of view, we meet with two facts of constant occurrence. When the quantity of ferment is too small in proportion to that of the sugar, its putrefaction will be completed before the transformation of all the sugar is effected. Some sugar here remains undecomposed, because the cause of its transformation is absent, viz. contact with a body in a state of decomposition.

But when the quantity of ferment predominates, a certain quantity of it remains after all the sugar has fermented, its decomposition proceeding very slowly, on account of its insolubility in water. This residue of ferment is still able to induce fermentation when introduced into a fresh solution of sugar, and retains the same power until it has passed through all the stages of its own transformation. Hence a certain quantity of yeast is necessary in order to effect the transformation of a certain portion of sugar, not because it acts by its quantity in increasing any affinity, but because its influence depends solely on its presence, and its presence is necessary, until the last atom of sugar is decomposed.

These facts and observations point out the existence of a new cause, which effects combinations and decompositions. This cause is the action which bodies in a state of combination or decomposition exercise upon substances, the component parts of which are united together by a feeble affinity. This action resembles a peculiar power, attached to a body in the state of combination or decomposition, but exerting its influence beyond the sphere of its own attractions. We are now able to account satisfactorily for many known phenomena.

A large quantity of hippuric acid may be obtained from the fresh urine of a horse, by the addition of muriatic acid; but when the urine has undergone putrefaction, no trace of it can be discovered. The urine of man contains a considerable quantity of urea; but when the urine putrefies, the urea entirely disappears. When urea is added to a solution of sugar in the state of fermentation, it is decomposed into carbonic acid and ammonia. No asparagin can be detected in a putrefied infusion of asparagin, liquorice-root, or the root of marshmallow (*Althæa officinalis.*

It has already been mentioned, that the strong affinity of nitrogen for hydrogen, and that of carbon for oxygen, are the cause of the facility with which the elements of azotised compounds are disunited; those affinities aiding each other, inasmuch as by virtue of them different elements of the compounds strive to take possession of the different elements of water. Now since it is found that no body destitute of nitrogen possesses, when pure, the property of decomposing spontaneously whilst in contact with water, we must ascribe this property which azotised bodies possess in so eminent a degree, to something peculiar in the nature of the compounds of nitrogen, and to their constituting, in a certain measure, more highly organized atoms.

Every azotised constituent of the animal or vegetable organism runs spontaneously into putrefaction, when exposed to moisture and a high temperature.

Azotised matters are, accordingly, the only causes of fermentation and putrefaction in vegetable substances.

Putrefaction, on account of its effects, as a mixed transformation of many different substances, may be classed with the most powerful processes of deoxidation, by which the strongest affinities are overcome.

When a solution of gypsum in water is mixed with a decoction of sawdust, or any other organic matter capable of putrefaction, and preserved in well-closed vessels, it is found after some time, that the solution contains no more sulphuric acid, but in its place carbonic and free hydro-sulphuric acid, between which the lime of the gypsum is shared. In stagnant water containing sulphates in solution, crystallised pyrites is observed to form on the decaying roots.

Now we know that in the putrefaction of wood under water, when air therefore is excluded, a part of its carbon combines with the oxygen of the water, as well as with the oxygen which the wood itself contains; whilst its hydrogen and that of the decomposed water are liberated either in a pure state, or as carburetted hydrogen. The products of this decomposition are of the same kind as those generated when steam is conducted over red-hot charcoal.

It is evident, that if with the water a substance containing a large quantity of oxygen, such as sulphuric acid, be also present, the matters in the state of putrefaction will make use of the oxygen of that substance as well as that of the water, in order to form carbonic acid; and the sulphur and hydrogen being set free will combine whilst in the nascent state, producing hydrosulphuric acid, which will be again decomposed if metallic oxides be present; and the results of this second decomposition will be water and metallic sulphurets.

The putrefied leaves of woad (*Isatis tinctoria,*) in contact with indigo-blue, water and alkalies, suffer farther decomposition, and the indigo is deoxidised and dissolved.

The mannite formed by the putrefaction of beet-roots and other plants which contain sugar, contains the same number of equivalents of carbon and hydrogen as the sugar of grapes, but two atoms less of oxygen; and it is highly probable that it is produced from sugar of grapes, contained in those plants, in precisely the same manner as indigo-blue is converted into deoxidised white indigo.

During the putrefaction of gluten, carbonic acid and pure hydrogen gas are evolved; phosphate, acetate, caseate, and lactate of ammonia being at the same time produced in such quantity, that the further decomposition of the gluten ceases. But when the supply of water is renewed, the decomposition begins again, and in addition to the salts just mentioned, carbonate of ammonia and a white crystalline matter resembling mica (caseous oxide) are formed, together with hydrosulphate of ammonia, and a mucilaginous substance coagulable by chlorine. *Lactic acid* is almost always produced by the putrefaction of organic bodies.

We may now compare fermentation and putrefaction with the decomposition which organic compounds suffer under the influence of a high temperature. Dry distillation would appear to be a process of combustion or oxidation going on in the interior of a substance, in which a part of the carbon unites with all or part of the oxygen of the compound, while other new compounds containing a large proportion of hydrogen are necessarily produced. Fermentation may be considered as a process of combustion or oxidation of a similar kind, taking place in a liquid between the elements of *the same matter*, at a very slightly elevated temperature; and putrefaction as a process of oxidation, in which the oxygen of *all* the substances present comes into play.

CHAPTER VI.

EREMACAUSIS, OR DECAY.

In organic nature, besides the processes of decomposition named fermentation and putrefaction, another and not less striking class of changes occurs, which bodies suffer from the influence of the air. This is the act of gradual combination of the combustible elements of a body with the oxygen of the air; a slow combustion or oxidation, to which we shall apply the term of *eremacausis*.

The conversion of wood into humus, the formation of acetic acid out of alcohol, nitrification, and numerous other processes, are of this nature. Vegetable juices of every kind, parts of animal and vegetable substances, moist sawdust, blood, &c., cannot be exposed to the air, without suffering immediately a progressive change of colour and properties, during which oxygen is absorbed. These changes do not take place when water is excluded, or when the substances are exposed to the temperature of 32°, and it has been observed that different bodies require different degrees of heat, in order to effect the absorption of oxygen, and, consequently, their eremacausis. The property of suffering this change is possessed in the highest degree by substances containing nitrogen.

When vegetable juices are evaporated by a gentle heat in the air, a brown or brownish-black substance is precipitated as a product of the action of oxygen upon them. This substance, which appears to possess similar properties from whatever juice it is obtained, has received the name of *extractive matter*; it is insoluble or very sparingly soluble in water, but is dissolved with facility by alkalies. By the action of air on solid animal or vegetable matters, a similar pulverulent brown substance is formed, and is known by the name of *humus*.

The conditions which determine the commencement of eremacausis are of various kinds. Many organic substances, particularly such as are mixtures of several more simple matters, oxidise in the air when simply moistened with water; others not until they are subjected to the action of alkalies; but the greatest part of them undergo this state of slow combustion or oxidation, when brought in contact with other decaying matters.

The eremacausis of an organic matter is retarded or completely arrested by all those substances which prevent fermentation or putrefaction. Mineral acids, salts of mercury, aromatic substances, empyreumatic oils, and oil of turpentine, possess a similar action in this respect. The latter substances have the same effect on decaying bodies as on phosphuretted hydrogen, the spontaneous inflammability of which they destroy.

Many bodies which do not decay when moistened with water, enter into eremacausis when in contact with an alkali. Gallic acid, hæmatin, and many other compounds, may be dissolved in water and yet remain unaltered; but if the smallest quantity of a free alkali is present, they acquire the property of attracting oxygen, and are converted into a brown substance like humus, evolving very frequently at the same time carbonic acid. (Chevreul.)

A very remarkable kind of eremacausis takes place in many vegetable substances, when they are exposed to the influence of air, water, and ammonia. They absorb oxygen very rapidly, and form splendid violet or red-coloured liquids, as in the case of orcin and erythrin. They now contain an azotised substance, not in the form of ammonia.

All these facts show that the action of oxygen seldom affects the carbon of decaying substances, and this corresponds exactly

to what happens in combustion at high temperatures. It is well known, for example, that when no more oxygen is admitted to a compound of carbon and hydrogen than is sufficient to combine with its hydrogen, the carbon is not burned, but is separated as lamp-black; while, if the quantity of oxygen is not sufficient even to consume all the hydrogen, new compounds are formed, such as naphthalin and similar matters, which contain a smaller proportion of hydrogen than those compounds of carbon and hydrogen which previously existed in the combustible substance.

There is no example of carbon combining directly with oxygen at common temperatures, but numerous facts show that hydrogen, in certain states of condensation, possesses that property. Lamp-black which has been heated to redness may be kept in contact with oxygen gas, without forming carbonic acid; but lamp-black, impregnated with oils which contain a large proportion of hydrogen, gradually becomes warm, and inflames spontaneously. The spontaneous inflammability of the charcoal used in the fabrication of gunpowder has been correctly ascribed to the hydrogen which it contains in considerable quantity; for during its reduction to powder, no trace of carbonic acid can be detected in the air surrounding it; it is not formed until the temperature of the mass has reached a red heat. The heat which produces the inflammation is therefore not caused by the oxidation of the carbon.

The substances which undergo eremacausis may be divided into two classes. The first class comprehends those substances which unite with the oxygen of the air, without evolving carbonic acid; and the second, such as emit carbonic acid by absorbing oxygen.

When the oil of bitter almonds is exposed to the air, it absorbs two equivalents of oxygen, and is converted into benzoic acid; but half of the oxygen absorbed combines with the hydrogen of the oil, and forms water, which remains in union with the anhydrous benzoic acid.[*]

But, although it appears very probable that the oxygen acts primarily and principally upon hydrogen, the most combustible constituent of organic matter in the state of decay; still it cannot thence be concluded that the carbon is quite devoid of the power to unite with oxygen, when every particle of it is surrounded with hydrogen, an element with which the oxygen combines with greater facility.

We know, on the contrary, that although nitrogen cannot be made to combine with oxygen directly, yet it is oxidized and forms nitric acid, when mixed with a large quantity of hydrogen, and burned in oxygen gas. In this case its affinity is evidently increased by the combustion of the hydrogen, which is in fact communicated to it. It is conceivable, that in a similar manner, the carbon may be directly oxidised in several cases, obtaining from its contact with hydrogen in eremacausis a property which it does not itself possess at common temperatures. But the formation of carbonic acid during the eremacausis of bodies containing hydrogen, must in most cases be ascribed to another cause. It appears to be formed in a manner similar to the formation of acetic acid, by the eremacausis of saliculite of potash.[*]

An alkaline solution of hæmatin being exposed to an atmosphere of oxygen, 0·2 grm. absorb 28·6 cubic centimetres of oxygen gas in twenty-four hours, the alkali acquiring at the same time 6 cubic centimetres of carbonic acid. (Chevreul.) But these 6 cubic centimetres of carbonic acid contain only an equal volume of oxygen, so that it is certain from this experiment that ¾ of the oxygen absorbed have not united with the carbon. It is highly probable, that during the oxidation of the hydrogen, a portion of the carbon had united with the oxygen contained in the hæmatin, and had separated from the other elements as carbonic acid.

The experiments of De Saussure upon the decay of woody fibre show that such a separation is quite possible. Moist woody fibre evolved one volume of carbonic acid for every volume of oxygen which it absorbed. It has just been mentioned that carbonic acid contains its own volume of oxygen. Now, woody fibre contains carbon and the elements of water, so that the result of the action of oxygen upon it is exactly the same as if pure charcoal had combined directly with oxygen. But the characters of woody fibre show, that the elements of water are not contained in it in the form of water; for, were this the case, starch, sugar, and gum must also be considered as hydrates of carbon.

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[*] According to the experiments of Döbereiner, 100 parts of pyrogallic acid absorbs 38·09 parts of oxygen when in contact with ammonia and water; the acid being changed in consequence of this absorption into a mouldy substance, which contains less oxygen than the acid itself. It is evident that the substance which is formed is not a higher oxide; and it is found, on comparing the quantity of the oxygen absorbed with that of the hydrogen contained in the acid, that they are exactly in the proportions for forming water.

When colourless orcin is exposed together with ammonia to the contact of oxygen gas, the beautiful red-coloured orcein is produced. Now, the only changes which take place here are, that the absorption of oxygen by the elements of orcin and ammonia causes the formation of water; 1 equivalent of orcin $\mathrm{C18\ H12\ O8}$, and 1 equivalent of ammonia $\mathrm{NH3}$, absorb 5 equivalents of oxygen, and 5 equivalents of water are produced, the composition of orcin being $\mathrm{C18\ H10\ O8\ N}$. (Dumas.) In this case it is evident, that the oxygen absorbed has united merely with the hydrogen.

[*] This salt, when exposed to a moist atmosphere, absorbs 3 atoms of oxygen; *melanic acid* is produced, a body resembling humus, in consequence of the formation of which, the elements of 1 atom of acetic acid are separated from the saliculous acid.

But if the hydrogen does not exist in woody fibre in the form of water, the direct oxidation of the carbon cannot be considered as at all probable, without rejecting all the facts established by experiment regarding the process of combustion at low temperatures.

If we examine the action of oxygen upon a substance containing a large quantity of hydrogen, such as alcohol, we find most distinctly, that the direct formation of carbonic acid is the last stage of its oxidation, and that it is preceded by a series of changes, the last of which is a complete combustion of the hydrogen. Aldehyde, acetic, formic, oxalic, and carbonic acids, form a connected chain of products arising from the oxidation of alcohol; and the successive changes which this fluid experiences from the action of oxygen may be readily traced in them. Aldehyde is alcohol *minus* hydrogen; acetic acid is formed by the direct union of aldehyde with oxygen. Formic acid and water are formed by the union of acetic acid with oxygen. When all the hydrogen is removed from this formic acid, oxalic acid is produced; and the latter acid is converted into carbonic acid by uniting with an additional portion of oxygen. All these products appear to be formed simultaneously, by the action of oxidising agents on alcohol; but it can scarcely be doubted, that the formation of the last product, the carbonic acid, does not take place until all the hydrogen has been abstracted.

The absorption of oxygen by drying oils certainly does not depend upon the oxidation of their carbon; for in raw nut-oil, for example, which was not free from mucilage and other substances, only twenty-one volumes of carbonic acid were formed for every 146 volumes of oxygen gas absorbed.

It must be remembered, that combustion or oxidation at low temperatures produces results quite similar to combustion at high temperatures *with limited access of air*. The most combustible element of a compound, which is exposed to the action of oxygen, must become oxidised first, for its superior combustibility is caused by its being enabled to unite with oxygen at a temperature at which the other elements cannot enter into that combination; this property having the same effect as a greater affinity.

The combustibility of potassium is no measure for its affinity for oxygen; we have reason to believe that the attraction of magnesium and aluminium for oxygen is greater than that of potassium for the same element; but neither of those metals oxidises either in air or water at common temperatures, whilst potassium decomposes water with great violence, and appropriates its oxygen.

Phosphorus and hydrogen combine with oxygen at ordinary temperatures, the first in moist air, the second when in contact with finely-divided platinum; while charcoal requires a red heat before it can enter into combination with oxygen. It is evident that phosphorus and hydrogen are more combustible than charcoal, that is, that their affinity for oxygen *at common temperatures* is greater; and this is not the less certain, because it is found, that carbon in certain other conditions shows a much greater affinity for oxygen than either of those substances.

In putrefaction, the conditions are evidently present, under which the affinity of carbon for oxygen comes into play; neither expansion, cohesion, nor the gaseous state, opposes it, whilst in eremacausis all these restraints have to be overcome.

The evolution of carbonic acid, during the decay or eremacausis of animal or vegetable bodies which are rich in hydrogen, must accordingly be ascribed to a transposition of the elements or disturbance in their attractions, similar to that which gives rise to the formation of carbonic acid in the processes of fermentation and putrefaction.

The eremacausis of such substances is, therefore, a decomposition analogous to the putrefaction of azotised bodies. For in these there are two affinities at play; the affinity of nitrogen for hydrogen, and that of carbon for oxygen, and both facilitate the disunion of the elements. Now there are two affinities also in action in those bodies which decay with the evolution of carbonic acid. One of these affinities is the attraction of the oxygen of the air for the hydrogen of the substance, which corresponds to the attraction of nitrogen for the same element; and the other is the affinity of the carbon of the substance for its oxygen, which is constant under all circumstances.

When wood putrefies in marshes, carbon and oxygen are separated from its elements in the form of carbonic acid, and hydrogen in the form of carburetted hydrogen. But when wood decays or putrefies in the air, its hydrogen does not combine with carbon, but with oxygen, for which it has a much greater affinity at common temperatures.

Now it is evident from the complete similarity of these processes, that decaying and putrefying bodies can mutually replace one another in their reciprocal actions.

All putrefying bodies pass into the state of decay, when exposed freely to the air, and all decaying matters into that of putrefaction when air is excluded. All bodies, likewise, in a state of decay are capable of inducing putrefaction in other bodies in the same manner as putrefying bodies them selves do.

CHAPTER VII.

EREMACAUSIS OR DECAY OF BODIES DESTITUTE OF NITROGEN: FORMATION OF ACETIC ACID.

ALL those substances which appear to possess the property of entering spontaneously into fermentation and putrefaction, do not in reality suffer those changes without some previous disturbance in the attraction of their elements. Eremacausis always precedes fermentation and putrefaction, and it is not until after the absorption of a certain quantity of oxygen that the signs of a transformation in the interior of the substances show themselves.

It is a very general error to suppose that organic substances have the power of undergoing change spontaneously, *without the aid of an external cause.* When they are not in a state of change, it is necessary, before they can assume that state, that the existing equilibrium of their elements should be disturbed; and the most common cause of this disturbance is undoubtedly the atmosphere which surrounds all bodies.

The juices of the fruit or other part of a plant which very readily undergo decomposition, retain their properties unchanged as long as they are protected from immediate contact with the air, that is, as long as the cells or organs in which they are contained resist the influence of the air. It is not until after the juices have been exposed to the air, and have absorbed a certain quantity of oxygen, that the substances dissolved in them begin to be decomposed.

The beautiful experiments of Gay-Lussac upon the fermentation of the juice of grapes, as well as the important practical improvements to which they have led, are the best proofs that the atmosphere possesses an influence upon the changes of organic substances. The juice of grapes which were expressed under a receiver filled with mercury, so that air was completely excluded, did not ferment. But when the smallest portion of air was introduced, a certain quantity of oxygen became absorbed, and fermentation immediately began. Although the juice was expressed from the grapes in contact with air, under the conditions therefore necessary to cause its fermentation, still this change did not ensue when the juice was heated in close vessels to the temperature of boiling water. When thus treated, it could be preserved for years without losing its property of fermenting. A fresh exposure to the air at any period caused it to ferment.

Animal food of every kind, and even the most delicate vegetables, may be preserved unchanged if heated to the temperature of boiling water in vessels from which the air is completely excluded. Food thus prepared has been kept for fifteen years, and upon opening the vessels after this long time, has been found as fresh and well-flavoured as when originally placed in them.

The action of the oxygen in these processes of decomposition is very simple; it excites changes in the composition of the azotised matters dissolved in the juices;—the mode of combination of the elements of those matters undergoes a disturbance and change in consequence of their contact with oxygen. The oxygen acts here in a similar manner to the friction or motion which affects the mutual decomposition of two salts, the crystallization of salts from their solution, or the explosion of fulminating mercury. It causes the state of rest to be converted into a state of motion.

When this condition of intestine motion is once excited, the presence of oxygen is no longer necessary. The smallest particle of an azotised body in this act of decomposition exercises an influence upon the particles in contact with it, and the state of motion is thus propagated through the substance. The air may now be completely excluded, but the fermentation or putrefaction proceeds uninterruptedly to its completion. It has been remarked that the mere contact of carbonic acid is sufficient to produce fermentation in the juices of several fruits.

The contact of ammonia and alkalies in general may be mentioned amongst the chemical conditions which determine the commencement of eremacausis; for their presence causes many substances to absorb oxygen and to decay, in which neither oxygen nor alkalies alone produce that change.

Thus alcohol does not combine with the oxygen of the air at common temperatures. But a solution of potash in alcohol absorbs oxygen with much rapidity, and acquires a brown colour. The alcohol is found after a short time to contain acetic acid, formic acid, and the products of the decomposition of aldehyde by alkalies, including aldehyde resin, which gives the liquid a brown colour.

The most general condition for the production of eremacausis in organic matter is contact with a body already in the state of eremacausis or putrefaction. We have here an instance of true contagion; for the communication of the state of combustion is in reality the effect of the contact.

It is decaying wood which causes fresh wood around it to assume the same condition, and it is the very finely divided woody fibre in the act of decay which in moistened gall-nuts converts the tannic acid with such rapidity into gallic acid.

A most remarkable and decided example of this induction of combustion has been observed by De Saussure. It has already been mentioned, that moist woody fibre, cotton, silk, or vegetable mould, in the act of fermentation or putrefaction, converts oxygen gas which may surround it into carbonic acid, without change of volume. Now, De Saussure added a certain quantity of hydrogen gas to the oxygen, and observed a diminution in volume immediately after the addition. A part of the hydrogen gas had disappeared, and along with it a portion of the oxygen, but a corresponding quantity of carbonic acid gas had not been formed. The hydrogen and oxygen had disappeared in exactly the same proportion as that in which they combine to form water; a true combustion of the hydrogen, therefore, had been induced by mere contact with matter in the state of eremacausis. The action of the decaying substance here produced results exactly similar to those effected by spongy platinum; but that they proceeded from a different cause was shown by the fact, that the presence of carbonic oxide, which arrests completely the action of platinum on carburetted hydrogen, did not retard in the slightest degree the combustion of the hydrogen in contact with the decaying bodies.

But the same bodies were found by De Saussure not to possess the property just described, before they were in a state of fermentation or decay; and he has shown that even when they are in this state, the presence of antiseptic matter destroys completely all their influence.

Let us suppose a volatile substance containing a large quantity of hydrogen to be substituted for the hydrogen gas in De Saussure's experiments. Now, the hydrogen in such compounds being contained in a state of greater condensation would suffer a more rapid oxidation, that is, its combustion would be sooner completed. This principle is in reality attended to in the manufactories in which acetic acid is prepared according to the new plan. In the process there adopted all the conditions are afforded for the eremacausis of alcohol, and for its consequent conversion into acetic acid.

The alcohol is exposed to a moderate heat, and spread over a very extended surface, but these conditions are not sufficient to effect its oxidation. The alcohol must be mixed with a substance which is with facility changed by the oxygen of the air, and either enters into eremacausis by mere contact with oxygen, or by its fermentation or putrefaction yields products possessed of this property. A small quantity of beer, acescent wine, a decoction of malt, honey, and numerous other substances of this kind, possess the action desired.

The difference in the nature of the substances which possess this property shows, that none of them can contain a peculiar matter which has the property of exciting eremacausis; they are only the bearers of an action, the influence of which extends beyond the sphere of its own attractions. Their power consists in a condition of decomposition or eremacausis, which impresses the same condition upon the atoms of alcohol in its vicinity; exactly as in the case of an alloy of platinum and silver dissolving in nitric acid, in which the platinum becomes oxidised, by virtue of an inductive action exercised upon it by the silver in the act of its oxidation. The hydrogen of the alcohol is oxidised at the expense of the oxygen in contact with it, and forms water, evolving heat at the same time; the residue is aldehyde, a substance which has as great an affinity for oxygen as sulphuric acid, and combines, therefore, directly with it, producing acetic acid.

CHAPTER VIII.

EREMACAUSIS OF SUBSTANCES CONTAINING NITROGEN. NITRIFICATION.

When azotised substances are burned at high temperatures, their nitrogen does not enter into direct combination with oxygen. The knowledge of this fact is of assistance in considering the process of the eremacausis of such substances. Azotised organic matter always contains carbon and hydrogen, both of which elements have a very strong affinity for oxygen.

Now nitrogen possesses a very feeble affinity for that element, so that its compounds during their combustion present analogous phenomena to those which are observed in the combustion of substances containing a large proportion of hydrogen and carbon; a separation of the carbon of the latter substances in an uncombined state takes place, and in the same way the substances containing nitrogen give out that element in its gaseous form.

When a moist azotised animal matter is exposed to the action of the air, ammonia is always liberated; nitric acid is never formed.

But when alkalies or alkaline bases are present, a union of oxygen with the nitrogen takes place under the same circumstances, and nitrates are formed together with the other products of oxidation.

Although we see the most simple means and direct methods employed in the great processes of decomposition which proceed in nature, still we find that the final result depends on a succession of actions, which are essentially influenced by the chemical nature of the bodies submitted to decomposition.

When it is observed that the character of a substance remains unaltered in a whole series of phenomena, there is no reason to ascribe a new character to it, for the purpose of explaining a single phenomenon, especially where the explanation of that according to known facts offers no difficulty.

The most distinguished philosophers suppose that the nitrogen in an animal substance, when exposed to the action of air, water, and alkaline bases, obtains the power to unite directly with oxygen, and form nitric acid, but we are not acquainted with a single fact which justifies this opinion. It is only by the interposition of a large quantity of hydrogen in the state of combustion or oxidation, that nitrogen can be converted into an oxide.

When a compound of nitrogen and carbon, such as cyanogen, is burned in oxygen gas, its carbon alone is oxidised; and when it is conducted over a metallic oxide heated to redness, an oxide of nitrogen is very rarely produced, and never when the carbon is in excess. Kuhlmann found in his experiments, that it was only when cyanogen was mixed with an excess of oxygen gas and conducted over spongy platinum, that nitric acid was generated.

Kuhlmann could not succeed in causing pure nitrogen to combine directly with oxygen, even under the most favourable circumstances; thus, with the aid of spongy platinum at different temperatures, no union took place.

The carbon in the cyanogen gas must, therefore, have given rise to the combustion of the nitrogen by induction.

On the other hand we find that ammonia (a compound of hydrogen and nitrogen) cannot be exposed to the action of oxygen, without the formation of an oxide of nitrogen, and in consequence the production of nitric acid.

It is owing to the great facility with which ammonia is converted into nitric acid, that it is so difficult to obtain a correct determination of the quantity of nitrogen in a compound subjected to analysis, in which it is either contained in the form of ammonia, or from which ammonia is formed by an elevation of temperature. For when ammonia is passed over red-hot oxide of copper, it is converted, either completely or partially, into binoxide of nitrogen.

When ammoniacal gas is conducted over peroxide of manganese or iron heated to redness, a large quantity of nitrate of ammonia is obtained, if the ammonia be in excess; and the same decomposition happens when ammonia and oxygen are together passed over red-hot spongy platinum.

It appears, therefore, that the combination of oxygen with nitrogen occurs rarely during the combustion of compounds of the latter element with carbon, but that nitric acid is always a product when ammonia is present in the substance exposed to oxidation.

The cause wherefore the nitrogen in ammonia exhibits such a strong disposition to become converted into nitric acid is undoubtedly that the two products, which are the result of the oxidation of the constituents of ammonia, possess the power of uniting with one another. Now this is not the case in the combustion of compounds of carbon and nitrogen; here one of the products is carbonic acid, which, on account of its gaseous form, must oppose the combination of the oxygen and nitrogen, by preventing their mutual contact, while the superior affinity of its carbon for the oxygen during the act of its formation will aid this effect.

When sufficient access of air is admitted during the combustion of ammonia, water is formed as well as nitric acid, and both of these bodies combine together. The presence of water may, indeed, be considered as one of the conditions essential to nitrification, since nitric acid cannot exist without it.

Eremacausis is a kind of putrefaction, differing from the common process of putrefaction, only in the part which the oxygen of the air plays in the transformations of the body in decay. When this is remembered, and when it is considered that in the transposition of the elements of azotised bodies their nitrogen assumes the form of ammonia, and that in this form, nitrogen possesses a much greater disposition to unite with oxygen than it has in any of its other compounds; we can with difficulty resist the conclusion, that ammonia is the general cause of nitrification on the surface of the earth.

Azotised animal matter is not, therefore, the immediate cause of nitrification, it contributes to the production of nitric acid only in so far as it is a slow and continued source of ammonia.

Now it has been shown in the former part of this work, that ammonia is always present in the atmosphere, so that nitrates might thence be formed in substances which themselves contained no azotised matter. It is known also, that porous substances possess generally the power of condensing ammonia; there are few ferruginous earths which do not evolve ammoniacal products when heated to redness, and ammonia is the cause of the peculiar smell perceived upon moistening aluminous minerals. Thus, ammonia, by being a constituent of the atmosphere, is a very widely diffused cause of nitrification, which will come into play whenever the different conditions necessary for the oxidation of ammonia are combined. It is probable that other organic bodies in the state of eremacausis are the means of causing the combustion of ammonia; at all events, the cases are very rare, in which nitric acid is generated from ammonia, in the absence of all matter capable of eremacausis.

From the preceding observations on the causes of fermentation, putrefaction, and decay, we may now draw several conclusions calculated to correct the views generally entertained respecting the fermentation of wine and beer, and several other important processes of decomposition which occur in nature.

CHAPTER IX.

ON VINOUS FERMENTATION:—WINE AND BEER.

It has already been mentioned, that fermentation is excited in the juice of grapes by the access of air; alcohol and carbonic acid being formed by the decomposition of the sugar contained in the fluid. But it was also stated, that the process once commenced, continues until all the sugar is completely decomposed, quite independently of any further influence of the air.

In addition to the alcohol and carbonic acid formed by the fermentation of the juice, there is also produced a yellow or gray insoluble substance, containing a large quantity of nitrogen. It is this body which possesses the power of inducing fermentation in a new solution of sugar, and which has in consequence received the name of *ferment*.

The alcohol and carbonic acid are produced from the elements of the sugar, and the ferment from those azotised constituents of the grape-juice, which have been termed gluten, or vegetable albumen.

According to the experiments of De Saussure, fresh impure gluten evolved, in five weeks, twenty-eight times its volume of a gas which consisted $\frac{3}{4}$ of carbonic acid, and $\frac{1}{4}$ of pure hydrogen gas; ammoniacal salts of several organic acids were formed at the same time. Water must, therefore, be decomposed during the putrefaction of gluten; the oxygen of this water must enter into combination with some of its constituents, whilst hydrogen is liberated, a circumstance which happens only in decompositions of the most energetic kind. Neither ferment nor any substance similar to it is formed in this case; and we have seen that in the fermentation of saccharine vegetable juices, no escape of hydrogen gas takes place.

It is evident that the decomposition which gluten suffers in an isolated state, and that which it undergoes when dissolved in a vegetable juice, belong to two different kinds of transformations. There is reason to believe that its change to the insoluble state depends upon an absorption of oxygen, for its separation in this state may be effected, under certain conditions, by free exposure to the air, without the presence of fermenting sugar. It is known also that the juice of grapes, or vegetable juices in general, become turbid when in contact with air, before fermentation commences; and this turbidity is owing to the formation of an insoluble precipitate of the same nature as ferment.

From the phenomena which have been observed during the fermentation of wort,[*] it is known with perfect certainty that ferment is formed from gluten at the same time that the transformation of the sugar is effected; for the wort contains the azotised matter of the corn, namely, gluten in the same condition as it exists in the juice of grapes. The wort ferments by the addition of yeast, but after its decomposition is completed, the quantity of ferment or yeast is found to be thirty times greater than it was originally.

Yeast from beer and that from wine, examined under the microscope, present the same form and general appearance. They are both acted on in the same manner by alkalies and acids, and possess the power of inducing fermentation anew in a solution of sugar; in short, they must be considered as identical.

The fact that water is decomposed during the putrefaction of gluten has been completely proved. The tendency of the carbon of the gluten to appropriate the oxygen of water must also always be in action, whether the gluten is decomposed in a soluble or insoluble state. These considerations, therefore, as well as the circumstance which all the experiments made on this subject appear to point out, that the conversion of gluten to the insoluble state is the result of oxidation, lead us to conclude that the oxygen consumed in this process is derived from the elements of water, or from the sugar which contains oxygen and hydrogen in the same proportion as water. At all events, the oxygen thus consumed in the fermentation of wine and beer is not taken from the atmosphere.

The fermentation of pure sugar in contact with yeast must evidently be a very different process from the fermentation of wort or *must.*[*]

In the former case, the yeast disappears during the decomposition of sugar; but in the latter, a transformation of gluten is effected at the same time, by which ferment is generated. Thus yeast is *destroyed* in the one case, but is *formed* in the other.

Now since no free hydrogen gas can be detected during the fermentation of beer and wine, it is evident that the oxidation of the gluten, that is, its conversion into ferment, must take place at the cost either of the oxygen of the water, or of that of the sugar; whilst the hydrogen which is set free must enter into new combinations, or by the deoxidation of the sugar, new compounds containing a large proportion of hydrogen, and small quantity of oxygen, together with the carbon of the sugar, must be formed.

It is well known that wine and fermented liquors generally contain, in addition to the alcohol, other substances which could not be detected before their fermentation, and which must have been formed, therefore, during that process in a manner similar to the production of mannite. The smell and taste which distinguished wine from all other fermented liquids are known to depend upon an ether of a volatile and highly combustible acid; the ether is of an oily nature, and has received the name *Œnanthic ether*. It is also ascertained that the smell and taste of brandy from corn and potato are owing to a peculiar oil, the *oil of potatoes*. This oil is more closely allied to alcohol in its properties, than to any other organic substance.

These bodies are products of the deoxidation of the substances dissolved in the fermenting liquids; they contain less oxygen than sugar or gluten, but are remarkable for the large quantity of hydrogen which enters into their composition.

Œnanthic acid contains an equal number of equivalents of carbon and hydrogen, exactly the same proportions of these elements, therefore, as sugar, but by no means the same proportion of oxygen. The oil of potatoes contains much more hydrogen.

Although it cannot be doubted that these volatile liquids are formed by a mutual interchange of the elements of gluten and sugar, in consequence, therefore, of a true process of putrefaction, still it is certain, that other causes exercise an influence upon their production and peculiarities.

The substances in wine to which its taste and smell are owing, are generated during the fermentation of the juice of such grapes as contain a certain quantity of tartaric acid; they are not found in wines which are free from all acid, or which contain a different organic acid, such as acetic acid.

The wines of warm climates possess no odour; wines grown in France have it in a marked degree, but in the wines from the Rhine the perfume is most intense. The kinds of grapes on the Rhine, which ripen very late, and scarcely ever completely, such as the *Riessling* and *Orleans*, have the strongest perfume or *bouquet*, and contain, proportionally, a larger quantity of tartaric acid. The earlier grapes, such as the *Rulander*, and others, contain a large proportion of alcohol, and are similar to Spanish wines in their flavour, but they possess no *bouquet*.

The grapes grown at the Cape, from Riesslings transplanted from the Rhine, produce an excellent wine, which does not, however, possess the aroma which distinguishes Rhenish wine.

It is evident from these facts, that the acid of wines, and their characteristic perfumes, have some connexion, for they are always found together; and it can scarcely be doubted that the presence of the former exercises a certain influence on the formation of the latter. This influence is very plainly observed in the fermentation of liquids, which are quite free from tartaric acid, and particularly of those which are nearly neutral or alkaline, such as the *mash*[*] of potatoes or corn.

The brandy obtained from corn and potatoes contains an ethereal oil of a similar composition in both, to which these liquors owe their peculiar smell. This oil is generated during the fermentation of the mash; it exists ready formed in the fermented liquids, and distils over with alcohol, when a gentle heat is applied.

It is observed that a greater quantity of alcohol is obtained when the mash is made quite neutral by means of ashes or carbonate of lime, but that the proportion of oil in the brandy is also increased.

Now it is known that brandy made from potato starch, which has been converted into sugar by dilute sulphuric acid, is completely free from the potato oil, so that this substance must be generated in consequence of a change suffered by the cellular tissue of the potatoes during their fermentation.

Experience has shown that the simultaneous fermentation or putrefaction of the cellular tissue, by which this oil is generated, may be completely prevented in the fabrication of brandy from corn.[*]

The same malt, which in the preparation of brandy yields a fluid containing the oil of which we are speaking, affords in the formation of beer a spirituous liquor, in which no trace of that oil can be detected. The principal difference in the preparation of the two liquids is, that in the fermentation of wort, an aromatic substance (hops) is added, and it is certain that its presence modifies the transformations which take place. Now it is known that the volatile oil of mustard, and the empyreumatic oils, arrest completely the action of yeast; and although the oil of hops does not possess this property, still it diminishes, in a great degree, the influence of decomposing azotised bodies upon the conversion of alcohol into acetic acid. There is, therefore, reason to believe that some aromatic substances, when added to fermenting mixtures, are capable of producing very various modifications in the nature of the products generated.

Whatever opinion, however, may be held regarding the origin of the volatile odoriferous substances obtained in the fermentation of wine, it is quite certain that the characteristic smell of wine is owing to an ether of an organic acid, resembling one of the fatty acids (œnanthic ether.)

It is only in liquids which contain other very soluble acids, that the fatty acids and œnanthic acids are capable of entering into combination with the ether of alcohol, and of thus producing compounds of a peculiar smell. This ether is found in all wines which contain free acid, and is absent from those in which no acids are present. This acid, therefore, is the means by which the smell is produced; since without its presence œnanthic ether could not be formed.

The greatest part of the oil of brandy made from corn consists of a fatty acid not converted into ether; it dissolves oxide of copper and metallic oxides in general, and combines with the alkalies.

The principal constituent of this oil is an acid identical in composition with œnanthic acid, but different in properties. (Mulder.) It is formed in fermenting liquids, which, if they be acid, contain only acetic acid, a body which has no influence in causing other acids to form ethers.

The oil of brandy made from potatoes is the hydrate of an organic base analogous to ether, and capable, therefore, of entering into combination with acids. It is formed in considerable quantity in fermenting liquids which are slightly alkaline; under circumstances, consequently, in which it is incapable of combining with an acid.

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[*] Wort is an infusion of malt; it consists of the soluble parts of this substance dissolved in water.

[*] The liquid expressed from grapes when fully ripe is called *must.*

[*] *Mash* is the mixture of malt, potatoes, and water, in the *mash tun*, a large vessel in which it is infused.

[*] In the manufactory of M. Dubrunfaut, so considerable a quantity of this oil is obtained under certain circumstances from brandy made from potatoes, that it might be employed for the purpose of illuminating his whole manufactory.

The products of the fermentation and putrefaction of neutral vegetable and animal matters are generally accompanied by substances of an offensive odour; but the most remarkable example of the generation of a true ethereal oil is seen in the fermentation of the *Herba centaurium minorius*, a plant which possesses no smell. When it is exposed in water to a slightly elevated temperature it ferments, and emits an agreeable penetrating odour. By the distillation of the liquid, an ethereal oily substance of great volatility is obtained, which excites a pricking sensation in the eyes, and a flow of tears. (Büchner.)

The leaves of the tobacco plant present the same phenomena; when fresh they possess very little or no smell. When they are subjected to distillation with water, a weak ammoniacal liquid is obtained, upon which a fatty crystallizable substance swims, which does not contain nitrogen, and is quite destitute of smell. But when the same plant, after being dried, is moistened with water, tied together in small bundles, and placed in heaps, a peculiar process of decomposition takes place. Fermentation commences, and is accompanied by the absorption of oxygen; the leaves now become warm and emit the characteristic smell of prepared tobacco and snuff. When the fermentation is carefully promoted and too high a heat avoided, this smell increases and becomes more delicate; and after the fermentation is completed, an oily azotised volatile matter called *nicotine* is found in the leaves. This substance—nicotine, which possesses all the properties of a base, was not present before the fermentation. The different kinds of tobacco are distinguished from one another, like wines, by having very different odoriferous substances, which are generated along with the nicotine.

We know that most of the blossoms and vegetable substances which possess a smell owe this property to a volatile oil existing in them; but it is not less certain, that others emit a smell only when they undergo change or decomposition.

Arsenic and arsenious acid are both quite inodorous. It is only during their oxidation that they emit their characteristic odour of garlic. The oil of the berries of the elder-tree, many kinds of oil of turpentine, and oil of lemons, possess a smell only during their oxidation or decay. The same is the case with many blossoms; and Geiger has shown, that the smell of musk is owing to its gradual putrefaction and decay.

It is also probable, that the peculiar odorous principle of many vegetable substances is newly formed during the fermentation of the saccharine juices of the plants. At all events, it is a fact, that very small quantities of the blossoms of the violet, elder, linden, or cowslip, added to a fermenting liquid, are sufficient to communicate a very strong taste and smell, which the addition of the water distilled from a quantity a hundred times greater would not effect. The various kinds of beer manufactured in Bavaria are distinguished by different flavours, which are given by allowing small quantities of the herbs and blossoms of particular plants to ferment along with the wort. On the Rhine, also, an artificial *bouquet* is often given to wine for fraudulent purposes, by the addition of several species of the sage and rue to the fermenting liquor; but the fictitious perfume thus obtained differs from the genuine aroma, by its inferior durability, and by being gradually dissipated.

The juice of grapes grown in different climates differs not only in the proportion of free acid which it contains, but also in respect of the quantity of sugar dissolved in it. The quantity of azotised matter in the juice seems to be the same in whatever part the grapes may grow; at least no difference has been observed in the amount of yeast formed during fermentation in the south of France, and on the Rhine.

The grapes grown in hot climates, as well as the boiled juice obtained from them, are proportionally rich in sugar. Hence, during the fermentation of the juice, the complete decomposition of its azotised matters, and their separation in the insoluble state, are effected before all the sugar has been converted into alcohol and carbonic acid. A certain quantity of the sugar consequently remains mixed with the wine in an undecomposed state, the condition necessary for its further decomposition being absent.

The azotised matters in the juice of grapes of the temperate zones, on the contrary, are not completely separated in the insoluble state, when the entire transformation of the sugar is effected. The wine of these grapes, therefore, does not contain sugar, but variable quantities of undecomposed gluten in solution.

This gluten gives the wine the property of becoming spontaneously converted into vinegar, when the access of air is not prevented. For it absorbs oxygen and becomes insoluble; and its oxidation is communicated to the alcohol, which is converted into acetic acid.

By allowing the wine to remain at rest in casks with a very limited access of air, and at the lowest possible temperature, the oxidation of this azotised matter is effected without the alcohol undergoing the same change, a higher temperature being necessary to enable alcohol to combine with oxygen. As long as the wine in the *stilling-casks* deposits yeast, it can still be caused to ferment by the addition of sugar, but old well-layed wine has lost this property, because the condition necessary for fermentation, namely, a substance in the act of decomposition or putrefaction, is no longer present in it.

In hotels and other places where wine is drawn gradually from a cask, and a proportional quantity of air necessarily introduced,

its eremacausis, that is, its conversion into acetic acid, is prevented by the addition of a small quantity of sulphurous acid. This acid, by entering into combination with the oxygen of the air contained in the cask, or dissolved in the wine, prevents the oxidation of the organic matter.

The various kinds of beer differ from one another in the same way as the wines.

English, French, and most of the German beers, are converted into vinegar when exposed to the action of air. But this property is not possessed by Bavarian beer, which may be kept in vessels only half filled without acidifying or experiencing any change. This valuable quality is obtained for it by a peculiar management of the fermentation of the wort. The perfection of experimental knowledge has here led to the solution of one of the most beautiful problems of the theory of fermentation.

Wort is proportionally richer in gluten than in sugar, so that during its fermentation in the common way, a great quantity of yeast is formed as a thick scum. The carbonic acid evolved during the process attaches itself to the particles of the yeast, by which they become specifically lighter than the liquid in which they are formed, and rise to its surface. Gluten in the act of oxidation comes in contact with the particles of the decomposing sugar in the interior of the liquid. The carbonic acid from the sugar and insoluble ferment from the gluten are disengaged simultaneously, and cohere together.

A great quantity of gluten remains dissolved in the fermented liquid, even after the transformation of the sugar is completed, and this gluten causes the conversion of the alcohol into acetic acid, on account of its strong disposition to attract oxygen, and to undergo decay. Now, it is plain, that with its separation, and that of all substances capable of attracting oxygen, the beer would lose the property of becoming acid. This end is completely attained in the process of fermentation adopted in Bavaria.

The wort, after having been treated with hops in the usual manner, is thrown into very wide flat vessels, in which a large surface of the liquid is exposed to the air. The fermentation is then allowed to proceed, while the temperature of the chambers in which the vessels are placed is never allowed to rise above 45 to 50° F. The fermentation lasts from three to six weeks, and the carbonic acid evolved during its continuance is not in large bubbles which burst upon the surface of the liquid, but in small bubbles like those which escape from a liquid saturated by high pressure. The surface of the wort is scarcely covered with a scum, and all the yeast is deposited on the bottom of the vessel in the form of a viscous sediment.

In order to obtain a clear conception of the great difference between the two kinds of fermentation, it may perhaps be sufficient to recall to mind the fact, that the transformation of gluten or other azotised matters is a process consisting of several stages. The first stage is the conversion of the gluten into insoluble ferment in the interior of the liquid, and as the transformation of the sugar goes on at the same time, carbonic acid and yeast are simultaneously disengaged. It is known with certainty, that this formation of yeast depends upon oxygen being appropriated by the gluten in the act of decomposition; but it has not been sufficiently shown whether this oxygen is derived from the water, sugar, or from the gluten itself; whether it combines directly with the gluten, or merely with its hydrogen, so as to form water. For the purpose of obtaining a definite idea of the process, we may designate the first change as the stage of oxidation. This oxidation of the gluten then, and the transposition of the atoms of the sugar into alcohol and carbonic acid, are necessarily attendant on each other, so that if the one is arrested the other must also cease.

Now, the yeast which rises to the surface of the liquid is not the product of a complete decomposition, but is oxidised gluten still capable of undergoing a new transformation by the transposition of its constituent elements. By virtue of this condition it has the power to excite fermentation in a solution of sugar; and if the gluten be also present, the decomposing sugar induces its conversion into fresh yeast, so that, in a certain sense, the yeast appears to reproduce itself.

Yeast of this kind is oxidised gluten in a state of *putrefaction*, and by virtue of this state it induces a similar transformation in the elements of the sugar.

The yeast formed during the fermentation of Bavarian beer is oxidised gluten in a state of *decay*. The process of decomposition which its constituents are suffering, gives rise to a very protracted putrefaction (*fermentation*) in the sugar. The intensity of the action is diminished in so great a degree, that the gluten which the fluid still holds in solution takes no part in it; the sugar in fermentation does not excite a similar state in the gluten.

But the contact of the already decaying and precipitated gluten or yeast causes the eremacausis of the gluten dissolved in the wort; oxygen gas is absorbed from the air, and all the gluten in solution is deposited as yeast.

The ordinary frothy yeast may be removed from fermenting beer by filtration, without the fermentation being thereby arrested; but precipitated yeast of Bavarian beer cannot be removed without the whole process of its fermentation being interrupted. The beer ceases to ferment altogether, or, if the temperature is raised, undergoes the ordinary fermentation.

The precipitated yeast does not excite ordinary fermentation, and consequently is quite unfitted for the purpose of baking; but the common frothy yeast can cause the kind of fermentation by which the former kind of yeast is produced.

When common yeast is added to wort at a temperature of between 40° and 45° F., a slow tranquil fermentation takes place, and a matter is deposited on the bottom of the vessel, which may be employed to excite new fermentation; and when the same operation is repeated several times in succession, the ordinary fermentation changes into that process by which only precipitated yeast is formed. The yeast now deposited has lost the property of exciting ordinary fermentation, but it produces the other process even at a temperature of 50° F.

In wort subjected to fermentation, at a low temperature, with this kind of yeast, the condition necessary for the transformation of the sugar is the presence of that yeast; but for the conversion of gluten into ferment by a process of oxidation, something more is required.

When the power of gluten to attract oxygen is increased by contact with precipitated yeast in a state of decay, the unrestrained access of air is the only other condition necessary for its own conversion into the same state of decay, that is for its oxidation. We have already seen that the presence of free oxygen and gluten are conditions which determine the eremacausis of alcohol and its conversion into acetic acid, but they are incapable of exerting this influence at low temperatures. A low temperature retards the slow combustion of alcohol, while the gluten combines spontaneously with the oxygen of the air, just as sulphuric acid does when dissolved in water. Alcohol undergoes no such change at low temperatures, but during the oxidation of the gluten in contact with it, is placed in the same condition as the gluten itself when sulphurous acid is added to the wine in which it is contained. The oxygen of the air unites both with the gluten and alcohol of wine not treated with sulphurous acid; but when this acid is present it combines with neither of them, being altogether absorbed by the acid. The same thing happens in the peculiar process of fermentation adopted in Bavaria. The oxygen of the air unites only with the gluten and not with the alcohol, although it would have combined with both at higher temperatures, so as to form acetic acid.

Thus, then, this remarkable process of fermentation with the precipitation of a mucous-like ferment consists of a simultaneous putrefaction and decay in the same liquid. The sugar is in the state of putrefaction, and the gluten in that of decay.

Appert's method of preserving food, and this kind of fermentation of beer, depend on the same principle.

In the fermentation of beer after this manner, all the substances capable of decay are separated from it by means of an unrestrained access of air, while the temperature is kept sufficiently low to prevent the alcohol from combining with oxygen. The removal of these substances diminishes the tendency of the beer to become acescent, or in other words, to suffer a farther transformation.

In Appert's mode of preserving food, oxygen is allowed to enter into combination with the substance of the food, at a temperature at which decay, but neither putrefaction nor fermentation, can take place. With the subsequent exclusion of the oxygen and the completion of the decay, every cause which could effect farther decomposition of the food is removed. The conditions for putrefaction are rendered insufficient in both cases; in the one by the removal of the substances susceptible of decay, in the other by the exclusion of the oxygen which would effect it.

It has been stated to be uncertain, whether gluten during its conversion into common yeast, that is, into the insoluble state in which it separates from fermenting liquids, really combines directly with oxygen. If it does combine with oxygen, then the difference between gluten and ferment would be, that the latter would contain a larger proportion of oxygen. Now it is very difficult to ascertain this, and even their analyses cannot decide the question. Let us consider, for example, the relations of alloxan and alloxantin* to one another. Both of these bodies contain the same elements as gluten, although in different proportions. Now they are known to be convertible into each other, by oxygen being absorbed in the one case, and in the other extracted. Both are composed of absolutely the same elements, in equal proportions; with the single exception, that alloxantin contains 1 equivalent of hydrogen more than alloxan.

When alloxantin is treated with chlorine and nitric acid, it is converted into alloxan, into a body, therefore, which is alloxantin *minus* 1 equivalent of hydrogen. If on the other hand a stream of sulphuretted hydrogen is conducted through alloxan, sulphur is precipitated, and alloxantin produced. It may be said, that in the first case hydrogen is abstracted, in the other added. But it would be quite as simple an explanation, if we considered them as oxides of the same radical: the alloxan being regarded as a combination of a body composed of $C^8 N^2 H^2 O^8$ with 2 equivalents of water, and alloxantin as a combination of 3 atoms of water, with a compound consisting of $C^8 N^2 H^2 O^7$. The conversion of alloxan into alloxantin would in this case result from its eight atoms of oxygen being reduced to seven, while alloxan would be formed out of alloxantin, by its combining with an additional atom of oxygen.

Now, oxides are known which combine with water, and present the same phenomena as alloxan and alloxantin. But no

compounds of hydrogen are known which form hydrates; and custom, which rejects all dissimilarity until the claim to peculiarity is quite proved, leads us to prefer an opinion, for which there is no farther foundation than that of analogy. The woad (*Isatis tinctoria*) and several species of the *Nerium* contain a substance similar in many respects to gluten, which is deposited as indigo blue, when an aqueous infusion of the dried leaves is exposed to the action of the air. Now it is very doubtful whether the blue insoluble indigo is an oxide of the colourless soluble indigo, or the latter a combination of hydrogen with the indigo blue. Dumas has found the same elements in both, except that the soluble compound contained 1 equivalent of hydrogen more than the blue.

In the same manner the soluble gluten may be considered a compound of hydrogen, which becomes ferment by losing a certain quantity of this element when exposed to the action of the oxygen of the air under favourable circumstances. At all events, it is certain that oxygen is the cause of the insoluble condition of gluten; for yeast is not deposited on keeping wine, or during the fermentation of Bavarian beer, unless oxygen has access to the fluid.

Now whatever be the form in which the oxygen unites with the gluten—whether it combines directly with it or extracts a portion of its hydrogen, forming water—the products formed in the interior of the liquid, in consequence of the conversion of the gluten into ferment, will still be the same. Let us suppose that gluten is a compound of another substance with hydrogen, then this hydrogen must be removed during the ordinary fermentation of must and wort, by combining with oxygen, exactly as in the conversion of alcohol into aldehyd by eremacausis.

In both cases the atmosphere is excluded; the oxygen cannot, then, be derived from the air, neither can it be supplied by the elements of water, for it is impossible to suppose that the oxygen will separate from the hydrogen of water, for the purpose of uniting with the hydrogen of gluten, in order again to form water. The oxygen must, therefore, be obtained from the elements of sugar, a portion of which substance must, in order to the formation of ferment, undergo a different decomposition from that which produces alcohol. Hence a certain part of the sugar will not be converted into carbonic acid and alcohol, but will yield other products containing less oxygen than sugar itself contains. These products, as has already been mentioned, are the cause of the great difference in the qualities of fermented liquids, and particularly in the quantity of alcohol which they contain.

Must and wort do not, therefore, in ordinary fermentation, yield alcohol in proportion to the quantity of sugar which they hold in solution, a part of the sugar being employed in the conversion of gluten into ferment, and not in the formation of alcohol. But in the fermentation of Bavarian beer all the sugar is expended in the production of alcohol; and this is especially the case whenever the transformation of the sugar is not accompanied by the formation of yeast.

It is quite certain that in the distilleries of brandy from potatoes, where no yeast is formed, or only a quantity corresponding to the malt which has been added, the proportion of alcohol and carbonic acid obtained during the fermentation of the *mash* corresponds exactly to that of the carbon contained in the starch. It is also known that the volume of carbonic acid evolved during the fermentation of beet-roots gives no exact indication of the proportion of sugar contained in them, for less carbonic acid is obtained than the same quantity of pure sugar would yield.

Beer obtained by the mode of fermentation adopted in Bavaria contains more alcohol, and possesses more intoxicating properties, than that made by the ordinary method of fermentation, when the quantities of malt used are the same. The strong taste of the former beer is generally ascribed to its containing carbonic acid in larger quantity, and in a state of more intimate combination; but this opinion is erroneous. Both kinds of beer are, at the conclusion of the fermentation, completely saturated with carbonic acid, the one as much as the other. Like all other liquids, they both must retain such a portion of the carbonic acid evolved as corresponds to their power of solution, that is, to their volumes.

The temperature of the fluid during fermentation has a very important influence on the quantity of alcohol generated. It has been mentioned, that the juice of beet-roots allowed to ferment at from 86° to 95° (30° to 35° C.) yields no alcohol; and that afterwards, in the place of the sugar, mannite, a substance incapable of fermentation, and containing very little oxygen, is found, together with lactic acid and mucilage. The formation of these products diminishes in proportion as the temperature is lower. But in vegetable juices, containing nitrogen, it is impossible to fix a limit, where the transformation of the sugar is undisturbed by any other process of decomposition.

It is known that in the fermentation of Bavarian beer the action of the oxygen of the air, and the low temperature, cause *complete* transformation of the sugar into alcohol; the cause which would prevent that result, namely, the extraction of the oxygen of part of the sugar by the gluten, in its conversion into ferment, being avoided by the introduction of oxygen from without.

The quantity of matters in the act of transformation is naturally greatest at the beginning of the fermentation of must and wort; and all the phenomena which accompany the process, such as evolution of gas, and heat, are best observed at that time. These signs of the changes proceeding in

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* Compounds obtained by the action of nitric acid on uric acid.

the fluid diminish when the greater part of the sugar has undergone decomposition; but they must cease entirely before the process can be regarded as completed.

The less rapid process of decomposition which succeeds the violent evolution of gas, continues in wine and beer until the sugar has completely disappeared; and hence it is observed, that the specific gravity of the liquid diminishes during many months. This slow fermentation, in most cases, resembles the fermentation of Bavarian beer, the transformation of the dissolved sugar being in part the result of a slow and continued decomposition of the precipitated yeast; but a complete separation of the azotised substances dissolved in it cannot take place when air is excluded.*

Neither alcohol alone, nor hops, nor indeed both together, preserve beer from becoming acid. The better kinds of ale and porter in England are protected from acidity, but at the loss of the interest of an immense capital. They are placed in large closed wooden vessels, the surfaces of which are covered with sand. In these they are allowed to lie for several years, so that they are treated in a manner exactly similar to wine during its *ripening*.

A gentle diffusion of air takes place through the pores of the wood, but the quantity of azotised substances being very great in proportion to the oxygen which enters, they consume it, and prevent its union with the alcohol. But the beer treated in this way does not keep for two months without acidifying, if it be placed in smaller vessels, to which free access of the air is permitted.

CHAPTER X.

DECAY OF WOODY FIBRE.

THE conversion of woody fibre into the substances termed humus and mould is, on account of its influence on vegetation, one of the most remarkable processes of decomposition which occur in nature.

Decay is not less important in another point of view; for, by means of its influence on dead vegetable matter, the oxygen which plants retained during life is again restored to the atmosphere.

The decomposition of woody fibre is effected in three forms, the results of which are different, so that it is necessary to consider each separately.

The first takes place when it is in the moist condition, and subject to free uninterrupted access of air; the second occurs when the air is excluded; and the third when the wood is covered with water, and in contact with putrefying organic matter.

It is known that woody fibre may be kept under water, or in dry air, for thousands of years without suffering any appreciable change; but that when brought into contact with air, in the moist condition, it converts the oxygen surrounding it into the same volume of carbonic acid, and is itself gradually changed into a yellowish brown, or black matter, of a loose texture.*

It has already been mentioned, that pure woody fibre contains carbon and the elements of water. Humus, however, is not produced by the decay of pure woody fibre, but by that of wood which contains foreign soluble and insoluble organic substances, besides its essential constituents.

The relative proportion of the component elements are, on this account, different in oak wood and in beech, and the composition of both of these differs very much from woody fibre, which is the same in all vegetables. The difference, however, is so trivial, that it may be altogether neglected in the consideration of the questions which will now be brought under discussion; besides, the quantity of the foreign substances is not constant, but varies according to the season of the year.

According to the careful analysis of Gay-Lussac and Thénard, 100 parts of oak wood, dried at 212° (100° C.,) from which all soluble substances had been extracted by means of water and alcohol, contained 52·53 parts of carbon, and 47·47 parts of hydrogen and oxygen, in the same proportion as they are contained in water.

Now it has been mentioned that moist wood acts in oxygen gas exactly as if its carbon combined directly with oxygen, and that the products of this action are carbonic acid and humus.

If the action of the oxygen were confined to the carbon of the wood, and if nothing but carbon were removed from it, the remaining elements would necessarily be found in the humus, unchanged except in the particular of being combined with less carbon. The final result of the action would therefore be a complete disappearance of the carbon, whilst nothing but the elements of water would remain.

But when decaying wood is subjected to examination in different stages of its decay,

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* The great influence which a rational management of fermentation exercises upon the quality of beer is well known in several of the German states. In the grand-duchy of Hesse, for example, a considerable premium is offered for the preparation of beer, according to the Bavarian method; and the premium is to be adjudged to any one who can prove that the beer brewed by him has lain for six months in the *store-vats* without becoming acid. Hundreds of casks of beer became changed to vinegar before an empirical knowledge of those conditions was obtained, the influence of which is rendered intelligible by the theory.

* According to the experiments of De Saussure, 240 parts of dry sawdust of oak wood convert 10 cubic inches of oxygen into the same quantity of carbonic acid, which contains 3 parts, by weight, of carbon; while the weight of the sawdust is diminished by 15 parts. Hence, 12 parts, by weight, of water, are at the same time separated from the elements of the wood.

the remarkable result is obtained, that the proportion of carbon in the different products augments. Consequently, if we did not take into consideration the evolution of carbonic acid under the influence of the air, the conversion of wood into humus might be viewed as a removal of the elements of water from the carbon.

The analysis of mouldered oak wood, which was taken from the interior of the trunk of an oak, and possessed a chocolate brown colour and the structure of wood, showed that 100 parts of it contained 53·36 parts of carbon and 46·44 parts of hydrogen and oxygen in the same relative proportions as in water. From an examination of mouldered wood of a light brown colour, easily reducible to a fine powder, and taken from another oak, it appeared that it contained 56·211 carbon and 43·789 water.

These indisputable facts point out the similarity of the decay of wood with the slow combustion or oxidation of bodies which contain a large quantity of hydrogen. Viewed as a kind of combustion, it would indeed be a very extraordinary process, if the carbon combined directly with the oxygen; for it would be a combustion in which the carbon of the burning body augmented constantly, instead of diminishing. Hence it is evident that it is the hydrogen which is oxidised at the expense of the oxygen of the air; while the carbonic acid is formed from the elements of the wood. Carbon never combines at common temperatures with oxygen, so as to form carbonic acid.

In whatever stage of decay wood may be, its elements must always be capable of being represented by their equivalent numbers. The following formula illustrates this fact with great clearness:

C36 H22 O22—oak wood, according to Gay-Lussac and Thénard.*
C35 H20 O20—humus from oak wood (Meyer.)†
C34 H18 O18—humus from oak wood (Dr. Will.)‡

It is evident from these numbers that for every two equivalents of hydrogen which are oxidised, two atoms of oxygen and one of carbon are set free.

Under ordinary circumstances, woody fibre requires a very long time for its decay; but this process is of course much accelerated by an elevated temperature and free unrestrained access of air. The decay, on the contrary, is much retarded by absence of moisture, and by the wood being surrounded with an atmosphere of carbonic acid, which prevents the access of air to the decaying matters.

Sulphurous acid, and all antiseptic substances, arrest the decay of woody fibre. It is well known that corrosive sublimate is employed for the purpose of protecting the timber of ships from decay; it is a substance which completely deprives vegetable or animal matters, the most prone to decomposition, of their property of entering into fermentation, putrefaction, or decay.

But the decay of woody fibre is very much accelerated by contact with alkalies or alkaline earths; for these enable substances to absorb oxygen, which do not possess this power themselves; alcohol, gallic acid, tannin, the vegetable colouring matters, and several other substances, are thus affected by them. Acids produce quite an opposite effect; they greatly retard decay.

Heavy soils, consisting of loam, retain longest the most important condition for the decay of the vegetable matter contained in them, viz., water; but their impermeable nature prevents contact with the air.

In moist sandy soils, particularly such as are composed of a mixture of sand and carbonate of lime, decay proceeds very quickly, it being aided by the presence of the slightly alkaline lime.

Now let us consider the decay of woody fibre during a very long period of time, and suppose that its cause is the gradual removal of the hydrogen in the form of water, and the separation of its oxygen in that of carbonic acid. It is evident that if we subtract from the formula C^{36}, H^{22}, O^{22}, the 22 equivalents of oxygen, with 11 equivalents of carbon, and 22 equivalents of hydrogen, which are supposed to be oxidised by the oxygen of the air, and separated in the form of water; then from 1 atom of oak wood, 25 atoms of pure carbon will remain as the final product of the decay. In other words, 100 parts of oak, which contain 52·5 parts of carbon, will leave as a residue 37 parts of carbon, which must remain unchanged, since carbon does not combine with oxygen at common temperatures.

But this final result is never attained in the decay of wood under common circumstances; and for this reason, that with the increase of the proportion of carbon in the residual humus, as in all decompositions of this kind, its attraction for the hydrogen, which still remains in combination, also increases, until at length the affinity of oxygen for the hydrogen is equalled by that of the carbon for the same element.

In proportion as the decay of woody fibre advances, its property of burning with flame, or in other words, of developing carburetted hydrogen on the application of heat, diminishes. Decayed wood burns without flame; whence no other conclusion can be drawn, than that the hydrogen, which analysis shows to be present, is not contained in it in the same form as in wood.

Decayed oak contains more carbon than fresh wood, but its hydrogen and oxygen are in the same proportion.

We would naturally expect that the flame given out by decayed wood should be more brilliant, in proportion to the increase of its carbon, but we find, on the contrary, that it burns like tinder, exactly as if no hydrogen were present. For the purposes of fuel, decayed or diseased wood is of little value, for it does not possess the property of burning with flame, a property upon which the advantages of common wood depend. The hydrogen of decayed wood must consequently be supposed to be in the state of water; for had it any other form, the characters we have described would not be possessed by the decayed wood.

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* The calculation gives 52·5 carbon, and 47·5 water.

† The calculation gives 54 carbon, and 46 water.

‡ The calculation gives 56 carbon, and 44 water.

If we suppose decay to proceed in a liquid, which contains both carbon and hydrogen, then a compound containing still more carbon must be formed, in a manner similar to the production of the crystalline colourless naphthalin from a gaseous compound of carbon and hydrogen. And if the compound thus formed were itself to undergo further decay, the final result must be the separation of carbon in a crystalline form.

Science can point to no process capable of accounting for the origin and formation of diamonds, except the process of decay. Diamonds cannot be produced by the action of fire, for a high temperature, and the presence of oxygen gas, would call into play their combustibility. But there is the greatest reason to believe that they are formed in the humid way, that is, in a liquid, and the process of decay is the only cause to which their formation can with probability be ascribed.

Amber, fossil resin, and the acids in mellite, are the products of vegetable matter which has suffered decomposition. They are found in wood or brown coal, and have evidently proceeded from the decomposition of substances which were contained in quite a different form in the living plants. They are all distinguished by the proportionally small quantity of hydrogen which they contain. The acid from mellite (mellitic acid) contains precisely the same proportions of carbon and oxygen as that from amber (succinic acid;) they differ only in the proportion of their hydrogen. M. Bromeis[*] found that succinic acid might be artificially formed by the action of nitric acid on stearic acid, a true process of eremacausis; the experiment was made in this laboratory (Giessen.)

CHAPTER XI.

VEGETABLE MOULD.

THE term *vegetable mould*, in its general signification, is applied to a mixture of disintegrated minerals, with the remains of animal and vegetable substances. It may be considered as earth in which humus is contained in a state of decomposition. Its action upon the air has been fully investigated by Ingenhouss and De Saussure.

When moist vegetable mould is placed in a vessel full of air, it extracts the oxygen therefrom with greater rapidity than decayed wood, and replaces it by an equal volume of carbonic acid. When this carbonic acid is removed and fresh air admitted, the same action is repeated.

Cold water dissolves only $\frac{1}{10,000}$th of its own weight of vegetable mould; and the residue left on its evaporation consists of common salt with traces of sulphate of potash and lime, and a minute quantity of organic matter, for it is blackened when heated to redness. Boiling water extracts several substances from vegetable mould, and acquires a yellow or yellowish brown colour, which is dissipated by absorption of oxygen from the air, a black flocculent deposit being formed. When the coloured solution is evaporated, a residue is left which becomes black on being heated to redness, and afterwards yields carbonate of potash when treated with water.

A solution of caustic potash becomes black when placed in contact with vegetable mould, and the addition of acetic acid to the coloured solution causes no precipitate or turbidity. But dilute sulphuric acid throws down a light flocculent precipitate of a brown or black colour, from which the acid can be removed with difficulty by means of water. When this precipitate, after having been washed with water, is brought whilst still moist under a receiver filled with oxygen, the gas is absorbed with great rapidity; and the same thing takes place when the precipitate is dried in the air. In the perfectly dry state it has entirely lost its solubility in water, and even alkalies dissolve only traces of it.

It is evident, therefore, that boiling water extracts a matter from vegetable mould, which owes its solubility to the presence of the alkaline salts contained in the remains of plants. This substance is a product of the incomplete decay of woody fibre. Its composition is intermediate between woody fibre and humus, into which it is converted, by being exposed in a moist condition to the action of the air.

CHAPTER XII.

ON THE MOULDERING OF BODIES.—PAPER, BROWN COAL, AND MINERAL COAL.

THE decomposition of wood, woody fibre, and all vegetable bodies when subjected to the action of water, and excluded from the air, is termed *mouldering*.

Wood, or brown coal and mineral coal, are the remains of vegetables of a former world; their appearance and characters show, that they are products of the processes of decomposition termed decay and putrefaction. We can easily ascertain by analysis the manner in which their constituents have been changed, if we suppose the greater part of their bulk to have been formed from woody fibre.

But it is necessary, before we can obtain a distinct idea of the manner in which coal is formed, to consider a peculiar change which woody fibre suffers by means of moisture, when partially or entirely excluded from the air.

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[*] Liebig's Annalen, Band xxxiv., Heft 3.

It is known, that when pure woody fibre, as linen, for example, is placed in contact with water, considerable heat is evolved, and the substance is converted into a soft friable mass which has lost all coherence. This substance was employed in the fabrication of paper before the use of chlorine, as an agent for bleaching. The rags employed for this purpose were placed in heaps, and it was observed, that on their becoming warm a gas was disengaged, and their weight diminished from 18 to 25 per cent.

When sawdust moistened with water is placed in a closed vessel, carbonic acid gas is evolved in the same manner as when air is admitted. A true putrefaction takes place, the wood assumes a white colour, loses its peculiar texture, and is converted into a rotten friable matter.

The white decayed wood found in the interior of trunks of dead trees which have been in contact with water, is produced in the way just mentioned.

An analysis of wood of this kind, obtained from the interior of the trunk of an oak, yielded, after having been dried at 212°,

Carbon	47·11	48·14
Hydrogen	6·31	6·06
Oxygen	45·31	44·43
Ashes	1·27	1·37
	100·00	100·00

Now, on comparing the proportions obtained from these numbers with the composition of oak wood, according to the analysis of Gay-Lussac and Thénard, it is immediately perceived, that a certain quantity of carbon has been separated from the constituents of wood, whilst the hydrogen is, on the contrary, increased. The numbers obtained by the analysis correspond very nearly to the formula C33 H27 O24.[*]

The elements of water have, therefore, become united with the wood, whilst carbonic acid is disengaged by the absorption of a certain quantity of oxygen.

If the elements of 5 atoms of water and 3 atoms of oxygen be added to the composition of the woody fibre of the oak, and 3 atoms of carbonic acid deducted, the exact formula for white mouldered wood is obtained.

Wood	C36	H22	O22
To this add 5 atoms of water		H 5	O 5
3 atoms of oxygen			O 3
	C36	H27	O30
Subtract from this 3 atoms carbonic acid	C 3		O 6
	C33	H27	O24

The process of mouldering is, therefore one of putrefaction and decay, proceeding simultaneously, in which the oxygen of the air and the component parts of water take part. But the composition of mouldered wood must change according as the access of oxygen is more or less prevented. White mouldered beech-wood yielded on analysis 47·67 carbon, 5·67 hydrogen, and 46·68 oxygen; this corresponds to the formula C33 H25 O24.

The decomposition of wood assumes, therefore, two different forms, according as the access of the air is free or restrained. In both cases carbonic acid is generated; and in the latter case, a certain quantity of water enters into chemical combination.

It is highly probable that in this putrefactive process, as well as in all others, the oxygen of the water assists in the formation of the carbonic acid.

Wood coal (brown coal of Werner) must have been produced by a process of decomposition similar to that of mouldering. But it is not easy to obtain wood coal suited for analysis, for it is generally impregnated with resinous or earthy substances, by which the composition of those parts which have been formed from woody fibre is essentially changed.

The wood coal, which forms extensive layers in the Wetterau (a district in Hesse Darmstadt,) is distinguished from that found in other places, by possessing the structure of wood unchanged, and by containing no bituminous matter. This coal was subjected to analysis, a piece being selected upon which the annual circle could be counted. It was obtained from the vicinity of Laubach; 100 parts contained

Carbon	57·28
Hydrogen	6·03
Oxygen	36·10
Ashes	0·59
	100·00

The large amount of carbon, and small quantity of oxygen, constitute the most obvious difference between this analysis and that of wood. It is evident that the wood which has undergone the change into coal must have parted with a certain portion of its oxygen. The proportions of these numbers are expressed by the formula C33 H21 O16.[*]

When these numbers are compared with those obtained by the analysis of oak, it would appear that the brown coal was produced from woody fibre by the separation of one equivalent of hydrogen, and the elements of three equivalents of carbonic acid.

1 atom wood	C36	H22	O22
Minus 1 atom hydrogen and 3 atoms carbonic acid	C 3	H 1	O 6
Wood coal,	C33	H21	O16

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[*] The calculation from this formula gives in 100 parts 47·9 carbon, 6·1 hydrogen, and 46 oxygen.

[*] The calculation gives 57·5 carbon, and 5·98 hydrogen.

All varieties of wood coal, from whatever strata they may be taken, contain more hydrogen than wood does, and less oxygen than is necessary to form water with this hydrogen; consequently they must all be produced by the same process of decomposition. The excess of hydrogen is either hydrogen of the wood which has remained in it unchanged, or it is derived from some exterior source. The analysis of wood coal from Ringkuhl, near Cassel, where it is seldom found in pieces with the structure of wood, gave, when dried at 212°,

Carbon	62·60	-	-	63·83
Hydrogen	5·02	-	-	4·80
Oxygen	26·52	-	-	25·51
Ashes	5·86	-	-	5·86
	100·00			100·00

The proportions derived from these numbers correspond very closely to the formula $C^{32} H^{15} O^{9}$, or they represent the constituents of wood, from which the elements of carbonic acid, water, and 2 equivalents hydrogen, have been separated.

$$\begin{array}{ll} & C_{36}H_{22}O_{22} + \text{Wood.} \\ \text{Subtract} & C_{4}H_{7}O_{13} + \text{4 atoms carbonic acid} + \\ & \qquad \text{5 atoms of water} \\ & \qquad \text{2 atoms of hydrogen.} \\ \hline & C_{32}H_{15}O_{9} = \text{Wood Coal from Ringkuhl.} \end{array}$$

The formation of both these specimens of wood coal appears from these formulæ to have taken place under circumstances which did not entirely exclude the action of the air, and consequent oxidation and removal of a certain quantity of hydrogen. Now the Laubacher coal is covered with a layer of basalt, and the coal of Ringkuhl was taken from the lowest seam of layers, which possess a thickness of from 90 to 120 feet; so that both may be considered as well protected from the air.

During the formation of brown coal, the elements of carbonic acid have been separated from the wood either alone, or at the same time with a certain quantity of water. It is quite possible that the difference in the process of decomposition may depend upon the high temperature and pressure under which the decomposition took place. At least, a piece of wood assumed the character and appearace of Laubacher coal, after being kept for several weeks in the boiler of a steam engine, and had then precisely the same composition. The change in this case was effected in water, at a temperature of from 334° to 352° F. (150°—160° C.,) and under a corresponding pressure. The ashes of the wood amounted to 0·51 per cent.; a little less, therefore, than those of the Laubacher coal; but this must be ascribed to the peculiar circumstances under which it was formed. The ashes of plants examined by Berthier amounted always to much more than this.

The peculiar process by which the decomposition of these extinct vegetables has been effected, namely, a disengagement of carbonic acid from their substance, appears still to go on at great depths in all the layers of wood coal. At all events it is remarkable that springs impregnated with carbonic acid occur in many places, in the country between Meissner, in the electorate of Hesse, and the Eifel, which are known to possess large layers of wood coal. These springs of mineral water are produced on the spot at which they are found; the springs of common water meeting with carbonic acid during their ascent, and becoming impregnated with it.

In the vicinity of the layers of wood coal at Salshausen (Hesse Darmstadt) an excellent acidulous spring of this kind existed a few years ago, and supplied all the inhabitants of that district; but it was considered advantageous to surround the sides of the spring with sandstone, and the consequence was, that all the outlets to the carbonic acid were closed, for this gas generally gains access to the water from the sides of the spring. From that time to the present this valuable mineral water has disappeared, and in its place is found a spring of common water.

Springs of water impregnated with carbonic acid occur at Schwalheim, at a very short distance from the layers of wood coal at Dorheim. M. Wilhelmi observed some time since, that they are formed of common spring water which ascends from below, and of carbonic acid which issues from the sides of the spring. This same fact has been shown to be the case in the famed Fachinger spring, by M. Schapper.

The carbonic acid gas from the springs in the Eifel is, according to Bischoff, seldom mixed with nitrogen or oxygen, and is probably produced in a manner similar to that just described. At any rate the air does not appear to take any part in the formation of these acidulous springs. The carbonic acid has evidently not been formed either by a combustion at high or low temperatures; for if it were so, the gas resulting from the combustion would necessarily be mixed with ⅘ of nitrogen, but it does not contain a trace of this element. The bubbles of gas which escape from these springs are absorbed by caustic potash, with the exception of a residuum too small to be appreciated.

The wood coal of Dorheim and Salzhausen must have been formed in the same way as that of the neighbouring village of Laubach; and since the latter contains the exact elements of woody fibre, minus a certain quantity of carbonic acid, its composition indicates very plainly the manner in which it has been produced.

The coal of the upper bed is subjected to an incessant decay by the action of the air, by means of which its hydrogen is removed in the same manner as in the decay of wood. This is recognised by the way in which it burns, and by the formation of carbonic acid in the mines.

The gases which are formed in mines of wood coal, and cause danger in their working, are not combustible or inflammable as in mines of mineral coal; but they consist generally of carbonic acid gas, and are very seldom intermixed with combustible gases.

Wood coal from the middle bed of the strata at Ringkuhl gave on analysis 65·40—64·01 carbon and 4·75—4·76* hydrogen; the proportion of carbon here is the same as in specimens procured from greater depths, but that of the hydrogen is much less.

Wood and mineral coal are always accompanied by iron pyrites (sulphuret of iron) or zinc blende (sulphuret of zinc;) which minerals are still formed from salts of sulphuric acid, with iron or zinc, during the putrefaction of all vegetable matter. It is possible that the oxygen of the sulphates in the layers of wood coal is the means by which the removal of the hydrogen is effected, since wood coal contains less of this element than wood.

According to the analysis of Richardson and Regnault, the composition of the combustible materials in splint coal from Newcastle, and cannel coal from Lancashire, is expressed by the formula $C_{24}H_{13}O$. When this is compared with the composition of woody fibre, it appears that these coals are formed from its elements, by the removal of a certain quantity of carburetted hydrogen and carbonic acid in the form of combustible oils. The composition of both of these coals is obtained by the subtraction of 3 atoms of carburetted hydrogen, 3 atoms of water, and 9 atoms of carbonic acid from the formula of wood.

$$\begin{array}{lr|l} & & C_{36}H_{22}O_{22} = \text{wood} \\ \text{3 atoms of carburetted hydrogen} & C_{3}\;H_{6} & \\ \text{3 atoms of water} & H_{3}\;O_{3} & \\ \text{9 atoms of carbonic acid} \;\; - \;\; - & C_{9}\;O_{18} & C_{12}H_{9}O_{21} \\ \hline & \text{Mineral coal} & C_{24}H_{13}O \end{array}$$

Carburetted hydrogen generally accompanies all mineral coal; other varieties of coal contain volatile oils which may be separated by distillation with water. (Reichenbach.) The origin of naphtha is owing to a similar process of decomposition. Caking coal from Caresfield, near Newcastle, contains the elements of cannel coal, *minus* the constituents of olefiant gas $C_{4}H_{4}$.

The inflammable gases which stream out of clefts in the strata of mineral coal, or in rocks of the coal formations, always contain carbonic acid, according to a recent examination by Bischoff, and also carburetted hydrogen, nitrogen, and olefiant gas; the last of which had not been observed, until its existence in these gases was pointed out by Bischoff. The analysis of *fire-damp* after it had been treated with caustic potash showed its constituents to be,

	Gas from an abandoned mine near Wallesweiler.	Gerbard's passage near Luisenthal.	Gas from a mine near Liekwege.
	Vol.	*Vol.*	*Vol.*
Light carburetted hydrogen	91·36	83.08	79·10
Olefiant gas	6·32	1·98	16·11
Nitrogen gas	2·32	14·94	4·79
	100·00	100·00	100·00

The evolution of these gases proves that changes are constantly proceeding in the coal.

It is obvious from this, that a continual removal of oxygen in the form of carbonic acid is effected from layers of wood coal, in consequence of which the wood must approach gradually to the composition of mineral coal. Hydrogen, on the contrary, is disengaged from the constituents of mineral coal in the form of a compound of carbo-hydrogen; a complete removal of all the hydrogen would convert coal into anthracite.

The formula $C_{36}H_{22}O_{22}$, which is given for wood, has been chosen as the empirical expression of the analysis, for the purpose of bringing all the transformations which woody fibre is capable of undergoing under one common point of view.

Now, although the correctness of this formula must be doubted, until we know with certainty the true constitution of woody fibre, this cannot have the smallest influence on the account given of the changes to which woody fibre must necessarily be subjected in order to be converted into wood or mineral coal. The theoretical expression refers to the quantity, the empirical merely to the relative *proportion* in which the elements of a body are united. Whatever form the first may assume, the empirical expression must always remain unchanged.

CHAPTER XIII.

ON POISONS, CONTAGIONS, AND MIASMS.

A GREAT many chemical compounds, some derived from inorganic nature, and others formed in animals and plants, produce peculiar changes or diseases in the living animal organism. They destroy the vital functions of individual organs; and when their action attains a certain degree of intensity, death is the consequence.

The action of inorganic compounds, such as acids, alkalies, metallic oxides, and salts, can in most cases be easily explained. They either destroy the continuity of particular organs, or they enter into combination with their substance. The action of sulphuric, muriatic, and oxalic acids, hydrate of potash, and all those substances which produce the direct destruction of the organs with which they come into contact, may be compared to a piece of iron, which can cause death by inflicting an injury on particular organs, either when heated to redness, or when in the form of a sharp knife. Such substances are not poisons in the limited sense of the word, for their injurious action depends merely upon their condition.

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* The analysis of brown coal from Ringkuhl, as well as all those of the same substance given in this work, have been executed in this laboratory by M. Kühnert of Cassel.

The action of the proper inorganic poisons is owing, in most cases, to the formation of a chemical compound by the union of the poison with the constituents of the organ upon which it acts; it is owing to an exercise of a chemical affinity more powerful than the vitality of the organ.

It is well to consider the action of inorganic substances in general, in order to obtain a clear conception of the mode of action of those which are poisonous. We find that certain soluble compounds, when presented to different parts of the body, are absorbed by the blood, whence they are again eliminated by the organs of secretion, either in a changed or in an unchanged state.

Iodide of potassium, sulpho-cyanuret of potassium, ferro-cyanuret of potassium, chlorate of potash, silicate of potash, and all salts with alkaline bases, when administered internally to man and animals in dilute solutions, or applied externally, may be again detected in the blood, sweat, chyle, gall, and splenic veins; but all of them are finally excreted from the body through the urinary passages.

Each of these substances, in its transit, produces a peculiar disturbance in the organism—in other words, they exercise a medicinal action upon it, but they themselves suffer no decomposition. If any of these substances enter into combination with any part of the body, the union cannot be of a permanent kind; for their reappearance in the urine shows that any compounds thus formed must have been again decomposed by the vital processes.

Neutral citrates, acetates, and tartrates of the alkalies, suffer change in their passage through the organism. Their bases can indeed be detected in the urine, but the acids have entirely disappeared, and are replaced by carbonic acid which has united with the bases. (Gilbert Blane and Wöhler.)

The conversion of these salts of organic acids into carbonates, indicates that a considerable qantity of oxygen must have united with their elements. In order to convert 1 equivalent of acetate of potash into the carbonate of the same base, 8 equivalents of oxygen must combine with it, of which either 2 or 4 equivalents (according as an acid or neutral salt is produced) remain in combination with the alkali; whilst the remaining 6 or 4 equivalents are disengaged as free carbonic acid. There is no evidence presented by the organism itself, to which these salts have been administered, that any of its proper constituents have yielded so great a quantity of oxygen as is necessary for their conversion into carbonates. Their oxidation can, therefore, only be ascribed to the oxygen of the air.

During the passage of these salts through the lungs, their acids take part in the peculiar process of eremacausis which proceeds in that organ; a certain quantity of the oxygen gas inspired unites with their constituents, and converts their hydrogen into water, and their carbon into carbonic acid. Part of this latter product (1 or 2 equivalents) remains in combination with the alkaline base, forming a salt which suffers no farther change by the process of oxidation; and it is this salt which is separated by the kidneys or liver.

It is manifest that the presence of these organic salts in the blood must produce a change in the process of respiration. A part of the oxygen inspired, which usually combines with the constituents of the blood, must, when they are present, combine with their acids, and thus be prevented from performing its usual office. The immediate consequence of this must be the formation of arterial blood in less quantity, or in other words, the process of respiration must be retarded.

Neutral acetates, tartrates, and citrates placed in contact with the air, and at the same time with animal or vegetable bodies in a state of eremacausis, produce exactly the same effects as we have described them to produce in the lungs. They participate in the process of decay, and are converted into carbonates just as in the living body. If impure solutions of these salts in water are left exposed to the air for any length of time, their acids are gradually decomposed, and at length entirely disappear.

Free mineral acids, or organic acids which are not volatile, and salts of mineral acids with alkaline bases, completely arrest decay when added to decaying matter in sufficient quantity; and when their quantity is small, the process of decay is protracted and retarded. They produce in living bodies the same phenomena as the neutral organic salts, but their action depends upon a different cause.

The absorption by the blood of a quantity of an inorganic salt sufficient to arrest the process of eremacausis in the lungs, is prevented by a very remarkable property of all animal membranes, skin, cellular tissue, muscular fibre, &c.; namely, by their incapability of being permeated by concentrated saline solutions. It is only when these solutions are diluted to a certain degree with water that they are absorbed by animal tissues.

A dry bladder remains more or less dry in saturated solutions of common salt, nitre, ferro-cyanuret of potassium, sulpho-cyanuret of potassium, sulphate of magnesia, chloride of potassium, and sulphate of soda. These solutions run off its surface in the same manner as water runs from a plate of glass besmeared with tallow.

Fresh flesh, over which salt has been strewed, is found after 24 hours' swimming in brine, although not a drop of water has

been added. The water has been yielded by muscular fibre itself, and having dissolved the salt in immediate contact with it, and thereby lost the power of penetrating animal substances, it has on this account separated from the flesh. The water still retained by the flesh contains a proportionally small quantity of salt, having that degree of dilution at which a saline fluid is capable of penetrating animal substances.

This property of animal tissues is taken advantage of in domestic economy for the purpose of removing so much water from meat that a sufficient quantity is not left to enable it to enter into putrefaction.

In respect of this physical property of animal tissues, alcohol resembles the inorganic salts. It is incapable of moistening, that is, of penetrating, animal tissues, and possesses such an affinity for water as to extract it from moist substances.

When a solution of a salt, in a certain degree of dilution, is introduced into the stomach, it is absorbed; but a concentrated saline solution, in place of being itself absorbed, extracts water from the organ, and a violent thirst ensues. Some interchange of water and salt takes place in the stomach; the coats of this viscus yield water to the solution, a part of which having previously become sufficiently diluted, is, on the other hand, absorbed. But the greater part of the concentrated solution of salt remains unabsorbed, and is not removed by the urinary passages; it consequently enters the intestines and intestinal canal, where it causes a dilution of the solid substances deposited there, and thus acts as a *purgative*.

Each of the salts just mentioned possesses this purgative action, which depends on a physical property shared by all of them; but besides this they exercise a medicinal action, because every part of the organism with which they come in contact absorbs a certain quantity of them.

The composition of the salts has nothing to do with their purgative action; it is quite a matter of indifference as far as the mere production of this action is concerned (not as to its intensity,) whether the base be potash or soda, or in many cases lime and magnesia; and whether the acid be phosphoric, sulphuric, nitric, or hydrochloric.

Besides these salts, the action of which does not depend upon their power of entering into combination with the component parts of the organism, there is a large class of others which, when introduced into the living body, effect changes of a very different kind, and produce diseases or death, according to the nature of these changes, without effecting a visible lesion of any organs.

These are the true inorganic poisons, the action of which depends upon their power of forming permanent compounds with the substance of the membranes, and muscular fibre.

Salts of lead, iron, bismuth, copper, and mercury, belong to this class.

When solutions of these salts are treated with a sufficient quantity of albumen, milk, muscular fibre, and animal membranes, they enter into combination with those substances, and lose their own solubility; while the water in which they were dissolved loses all the salt which it contained.

The salts of alkaline bases extract water from animal substances; whilst the salts of the heavy metallic oxides are, on the contrary, extracted from the water, for they enter into combination with the animal matters.

Now, when these substances are administered to an animal, they lose their solubility by entering into combination with the membranes, cellular tissue, and muscular fibre; but in very few cases can they reach the blood. All experiments instituted for the purpose of determining whether they pass into the urine have failed to detect them in that secretion. In fact, during their passage through the organism, they come into contact with many substances by which they are retained.

The action of corrosive sublimate and arsenious acid is very remarkable in this respect. It is known that these substances possess, in an eminent degree, the property of entering into combination with all parts of animal and vegetable bodies, rendering them at the same time insusceptible of decay or putrefaction. Wood and cerebral substance are both bodies which undergo change with great rapidity and facility when subject to the influence of air and water; but if they are digested for some time with arsenious acid or corrosive sublimate, they may subsequently be exposed to all the influences of the atmosphere without altering in colour or appearance.

It is farther known that those parts of a body which come in contact with these substances during poisoning, and which therefore enter into combination with them, do not afterwards putrefy; so that there can be no doubt regarding the cause of their poisonous qualities.

It is obvious that if arsenious acid and corrosive sublimate are not prevented by the vital principle from entering into combination with the component parts of the body, and consequently from rendering them incapable of decay and putrefaction, they must deprive the organs of the principal property which appertains to their vital condition, viz. that of suffering and effecting transformations; or, in other words, organic life must be destroyed. If the poisoning is merely superficial, and the quantity of the poison so small that only individual parts of the body which are capable of being regenerated have entered into combination with it, then eschars are produced—a phenomenon of a secondary kind—the compounds of the dead tissues with the poison being thrown off by the healthy parts. From these considerations it may readily be inferred that all internal signs of poisoning are variable and uncertain; for cases may happen, in which no apparent indication of change can be detected by simple observations of the parts, because, as has been already remarked, death may occur without the destruction of any organs.

When arsenious acid is administered in solution, it may enter into the blood. If a vein is exposed and surrounded with a solution of this acid, every blood-globule will combine with it, that is, will become poisoned.

The compounds of arsenic, which have not the property of entering into combination with the tissues of the organism, are without influence on life, even in large doses. Many insoluble basic salts of arsenious acid are known not to be poisonous. The substance called alkargen, discovered by Bunsen, has not the slightest injurious action upon the organism; yet it contains a very large quantity of arsenic, and approaches very closely in composition to the organic arsenious compounds found in the body.

These considerations enable us to fix with tolerable certainty the limit at which the above substances cease to act as poisons. For since their combination with organic matters must be regulated by chemical laws, death will inevitably result, when the organ in contact with the poison finds sufficient of it to unite with atom for atom; whilst if the poison is present in smaller quantity, a part of the organ will retain its vital functions.

According to the experiments of Mulder,* the equivalent in which fibrin combines with muriatic acid, and with the oxides of lead and copper, is expressed by the number 6361. It may be assumed therefore approximatively, that a quantity of fibrin corresponding to the number 6361 combines with 1 equivalent of arsenious acid, or 1 equivalent of corrosive sublimate.

When 6361 parts of anhydrous fibrin are combined with 30,000 parts of water, it is in the state in which it is contained in muscular fibre or blood in the human body. 100 grains of fibrin in this condition would form a neutral compound of equal equivalents with $3\frac{4}{10}$ grains of arsenious acid, and 5 grains of corrosive sublimate.

The atomic weight of the albumen of eggs and of the blood deduced from the analysis of the compound which it forms with oxide of silver is 7447, and that of animal gelatin 5652.

100 grains of albumen containing all the water with which it is combined in the living body, should consequently combine with $1\frac{1}{4}$ grain of arsenious acid.

These proportions which may be considered as the highest which can be adopted, indicate the remarkably high atomic weights of animal substances, and at the same time teach us what very small quantities of arsenious acid or corrosive sublimate are requisite to produce deadly effects.

All substances administered as antidotes in cases of poisoning, act by destroying the power which arsenious acid and corrosive sublimate possess, of entering into combination with animal matters, and of thus acting as poisons. Unfortunately no other body surpasses them in that power, and the compounds which they form can only be broken up by affinities so energetic, that their action is as injurious as that of the above-named poisons themselves. The duty of the physician consists, therefore, in his causing those parts of the poison which may be free and still uncombined, to enter into combination with some other body, so as to produce a compound incapable of being decomposed or digested in the same conditions. Hydrated peroxide of iron is an invaluable substance for this purpose.

When the action of arsenious acid or corrosive sublimate is confined to the surface of an organ, those parts only are destroyed which enter into combination with it; an eschar is formed, which is gradually thrown off.

Soluble salts of silver would be quite as deadly a poison as corrosive sublimate, did not a cause exist in the human body by which their action is prevented, unless their quantity is very great. This cause is the presence of common salt in all animal liquids. Nitrate of silver, it is well known, combines with animal substances, in the same manner as corrosive sublimate, and the compounds formed by both are exactly similar in the character of being incapable of decay or putrefaction.

When nitrate of silver in a state of solution is applied to skin or muscular fibre, it combines with them instantaneously; animal substances dissolved in any liquid are precipitated by it, and rendered insoluble, or, as it is usually termed, they are coagulated. The compounds thus formed are colourless, and so stable, that they cannot be decomposed by other powerful chemical agents. They are blackened by exposure to light, like all other compounds of silver, in consequence of a part of the oxide of silver which they contain being reduced to the metallic state. Parts of the body which have united with salts of silver no longer belong to the living organism, for their vital functions have been arrested by combination with oxide of silver; and if they are capable of being reproduced, the neighbouring living structures throw them off in the form of an eschar.

When nitrate of silver is introduced into the stomach, it meets with common salt and free muriatic acid; and if its quantity is not too great, it is immediately converted into chloride of silver—a substance which is absolutely insoluble in pure water. In a solution of salt or muriatic acid, however, chloride of silver does dissolve in extremely minute quantity; and it is this small part which exercises a medicinal influence when nitrate of silver is administered; the remaining chloride of silver is eliminated from the body in the ordinary way. Solubility is necessary to give efficacy to any substance in the human body.

The soluble salts of lead possess many properties in common with the salts of silver and mercury; but all compounds of lead with organic matters are capable of decomposition by dilute sulphuric acid. The disease called *painter's colic* is unknown in all manufactories of white lead in which the workmen are accustomed to take as a preservative *sulphuric acid lemonade* (a solution of sugar rendered acid by sulphuric acid.)

The organic substances which have combined in the living body with metallic oxides or metallic salts, lose their property of imbibing water and retaining it, without at the same time being rendered incapable of permitting liquids to penetrate through their pores. A strong contraction and shrinking of the surface is the general effect of contact with these metallic bodies. But corrosive sublimate, and several of the salts of lead, possess a peculiar property, in addition to those already mentioned. When they are present in excess, they dissolve the first formed insoluble compounds, and thus produce an effect quite the reverse of contraction, namely, a softening of the part of the body on which they have acted.

Salts of oxide of copper, even when in combination with the most powerful acids, are reduced by many vegetable substances, particularly such as sugar and honey, either into metallic copper, or into the red suboxide, neither of which enters into combination with animal matter. It is well known that sugar has been long employed as the most convenient antidote for poisoning by copper.

With respect to some other poisons, namely, hydrocyanic acid and the organic bases *strychnia* and *brucia*, we are acquainted with no facts calculated to elucidate the nature of their action. It may, however, be presumed with much certainty, that experiments upon their mode of action on different animal substances would very quickly lead to the most satisfactory conclusions regarding the cause of their poisonous effects.

There is a peculiar class of substances, which are generated during certain processes of decomposition, and which act upon the animal economy as deadly poisons, not on account of their power of entering into combination with it, or by reason of their containing a poisonous material, but solely by virtue of their peculiar condition.

In order to attain to a clear conception of the mode of action of these bodies, it is necessary to call to mind the cause on which we have shown the phenomena of fermentation, decay, and putrefaction to depend.

This cause may be expressed by the following law, long since proposed by La Place and Berthollet, although its truth with respect to chemical phenomena has only lately been proved. "*A molecule set in motion by any power can impart its own motion to another molecule with which it may be in contact.*"

This is a law of dynamics, the operation of which is manifest in all cases, in which the resistance (*force*, *affinity*, or *cohesion*,) opposed to the motion is not sufficient to overcome it.

We have seen that ferment or yeast is a body in the state of decomposition, the atoms of which, consequently, are in a state of motion or transposition. Yeast placed in contact with sugar communicates to the elements of that compound the same state, in consequence of which, the constituents of the sugar arrange themselves into new and simpler forms, namely, into alcohol and carbonic acid. In these new compounds the elements are united together by stronger affinities than they were in the sugar, and therefore under the conditions in which they were produced further decomposition is arrested.

We know, also, that the elements of sugar assume totally different arrangements, when the substances which excite their transposition are in a different state of decomposition from the yeast just mentioned. Thus, when sugar is acted on by rennet or putrefying vegetable juices, it is not converted into alcohol and carbonic acid, but into lactic acid, mannite, and gum.

Again, it has been shown, that yeast added to a solution of pure sugar gradually disappears, but that when added to vegetable juices which contain gluten as well as sugar, it is reproduced by the decomposition of the former substance.

The yeast with which these liquids are made to ferment has itself been originally produced from gluten.

The conversion of gluten into yeast in these vegetable juices is dependent on the decomposition (fermentation) of sugar; for, when the sugar has completely disappeared, any gluten which may still remain in the liquid does not suffer change from contact with the newly-deposited yeast, but retains all the characters of gluten.

Yeast is a product of the decomposition of gluten; but it passes into a second stage of decomposition when in contact with water. On account of its being in this state of further change, yeast excites fermentation in a fresh solution of sugar, and if this second saccharine fluid should contain gluten, (should it be *wort*, for example,) yeast is again generated in consequence of the transposition of the elements of the sugar exciting a similar change in this gluten.

After this explanation, the idea that yeast reproduces itself as seeds reproduce seeds, cannot for a moment be entertained.

From the foregoing facts it follows, that a body in the act of decomposition (it may be named the *exciter*,) added to a mixed fluid in which its constituents are contained, can reproduce itself in that fluid, exactly in the same manner as new yeast is produced when yeast is added to liquids containing gluten. This must be more certainly effected when the liquid acted upon contains the body by the metamorphosis of which the *exciter* has been originally formed.

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* Poggendorff's Annalen, Band xl. S. 259.

It is also obvious, that if the *exciter* be able to impart its own state of transformation to one only of the component parts of the mixed liquid acted upon, its own reproduction may be the consequence of the decomposition of this one body.

This law may be applied to organic substances forming part of the animal organism. We know that all the constituents of these substances are formed from the blood, and that the blood by its nature and constitution is one of the most complex of all existing matters.

Nature has adapted the blood for the reproduction of every individual part of the organism; its principal character consists in its component parts being subordinate to every attraction. These are in a perpetual state of change or transformation, which is effected in the most various ways through the influence of the different organs.

The indivdual organs, such as the stomach, cause all the organic substances conveyed to them which are capable of transformation to assume new forms. The stomach compels the elements of these substances to unite into a compound fitted for the formation of the blood. But the blood possesses no power of causing transformations; on the contrary, its principal character consists in its readily suffering transformations; and no other matter can be compared in this respect with it.

Now it is a well-known fact, that when blood, cerebral substance, gall, pus, and other substances in a state of putrefaction, are laid upon fresh wounds, vomiting, debility, and at length death, are occasioned. It is also well known that bodies in anatomical rooms frequently pass into a state of decomposition which is capable of imparting itself to the living body, the smallest cut with a knife which has been used in their dissection producing in these cases dangerous consequences.

The poison of bad sausages belongs to this class of noxious substances. Several hundred cases are known in which death has occurred from the use of this kind of food. In Würtemberg especially these cases are very frequent, for there the sausages are prepared from very various materials. Blood, liver, bacon, brains, milk, meal, and bread, are mixed together with salt and spices; the mixture is then put into bladders or intestines, and after being boiled is smoked.

When these sausages are well prepared, they may be preserved for months, and furnish a nourishing savoury food; but when the spices and salt are deficient, and particularly when they are smoked too late or not sufficiently, they undergo a peculiar kind of putrefaction, which begins at the centre of the sausage. Without any appreciable escape of gas taking place they become paler in colour, and more soft and greasy in those parts which have undergone putrefaction, and they are found to contain free lactic acid, or lactate of ammonia; products which are universally formed during the putrefaction of animal and vegetable matters.

The cause of the poisonous nature of these sausages was ascribed at first to hydrocyanic acid, and afterwards to sebacic acid, although neither of these substances had been detected in them. But sebacic acid is no more poisonous than benzoic acid, with which it has so many properties in common; and the symptoms produced are sufficient to show that hydrocyanic acid is not the poison.

The death which is the consequence of poisoning by putrefied sausages succeeds very lingering and remarkable symptoms. There is a gradual wasting of muscular fibre, and of all the constituents of the body similarly composed; the patient becomes much emaciated, dries to a complete mummy, and finally dies. The carcase is stiff as if frozen, and is not subject to putrefaction. During the progress of the disease the saliva becomes viscous and acquires an offensive smell.

Experiments have been made for the purpose of ascertaining the presence of some matter in the sausages to which their poisonous action could be ascribed; but no such matter has been detected. Boiling water and alcohol completely destroy the poisonous properties of the sausages, without themselves acquiring similar properties.

Now this is the peculiar character of all substances which exert an action by virtue of their existing condition—of those bodies the elements of which are in the state of decomposition or transposition; a state which is destroyed by boiling water and alcohol without the cause of the influence being imparted to those liquids; for a state of action or power cannot be preserved in a liquid.

Sausages, in the state here described, exercise an action upon the organism, in consequence of the stomach and other parts with which they come in contact not having the power to arrest their decomposition; and entering the blood in some way or other, while still possessing their whole power, they impart their peculiar action to the constituents of that fluid.

The poisonous properties of decayed sausages are not destroyed by the stomach as those of the small-pox virus are. All the substances in the body capable of putrefaction are gradually decomposed during the course of the disease, and after death nothing remains except fat, tendons, bones, and a few other substances which are incapable of

putrefying in the conditions afforded by the body.

It is impossible to mistake the *modus operandi* of this poison, for Colin has clearly proved that muscle, urine, cheese, cerebral substance, and other matters, in a state of putrefaction, communicate their own state of decomposition to substances much less prone to change of composition than the blood. When placed in contact with a solution of sugar, they cause its putrefaction, or the transposition of its elements into carbonic acid and alcohol.

When putrefying muscle or pus is placed upon a fresh wound, it occasions disease and death. It is obvious that these substances communicate their own state of putrefaction to the sound blood *from which they were produced*, exactly in the same manner as gluten in a state of decay or putrefaction causes a similar transformation in a solution of sugar.

Poisons of this kind are even generated by the body itself in particular diseases. In small-pox, plague, and syphilis, substances of a peculiar nature are formed from the constituents of the blood. These matters are capable of inducing in the blood of a healthy individual a decomposition similar to that of which they themselves are the subjects; in other words, they produce the same disease. The morbid virus appears to reproduce itself just as seeds appear to reproduce seeds.

The mode of action of a morbid virus exhibits such a strong similarity to the action of yeast upon liquids containing sugar and gluten, that the two processes have been long since compared to one another, although merely for the purpose of illustration. But when the phenomena attending the action of each respectively are considered more closely, it will in reality be seen that their influence depends upon the same cause.

In dry air, and in the absence of moisture, all these poisons remain for a long time unchanged; but when exposed to the air in the moist condition, they lose very rapidly their peculiar properties. In the former case, those conditions are afforded which arrest their decomposition without destroying it; in the latter, all the circumstances necessary for the completion of their decomposition are presented.

The temperature at which water boils, and contact with alcohol, render such poisons inert. Acids, salts of mercury, sulphurous acid, chlorine, iodine, bromine, aromatic substances, volatile oils, and particularly empyreumatic oils, smoke, and a decoction of coffee, completely destroy their contagious properties, in some cases combining with them or otherwise effecting their decomposition. Now all these agents, without exception, retard fermentation, putrefaction, and decay, and when present in sufficient quantity, completely arrest these processes of decomposition.

A peculiar matter, to which the poisonous action is due, cannot, we have seen, be extracted from decayed sausages: and it is equally impossible to obtain such a principle from the virus of small-pox or plague, and for this reason, that their peculiar power is due to an active condition recognisable by our senses, only through the phenomena which it produces.

In order to explain the effects of contagious matters, a peculiar principle of life has been ascribed to them—a life similar to that possessed by the germ of a seed, which enables it under favourable conditions to develope and multiply itself. It would be impossible to find a more correct figurative representation of these phenomena; it is one which is applicable to contagions, as well as to ferment, to animal and vegetable substances in a state of fermentation, putrefaction or decay, and even to a piece of decaying wood, which by mere contact with fresh wood, causes the latter to undergo gradually the same change and become decayed and mouldered.

If the property possessed by a body of producing such a change in any other substance as causes the reproduction of itself, with all its properties, be regarded as life, then, indeed, all the above phenomena may be ascribed to life. But in that case they must not be considered as the only processes due to vitality, for the above interpretation of the expression embraces the majority of the phenomena which occur in organic chemistry. Life would, according to that view, be admitted to exist in every body in which chemical forces act.

If a body A, for example *oxamide*, (a substance scarcely soluble in water, and without the slightest taste,) be brought into contact with another compound B, which is to be reproduced; and if this second body be *oxalic acid dissolved* in water; then the following changes are observed to take place:—The oxamide is decomposed by the oxalic acid, provided the conditions necessary for their exercising an action upon one another are present. The elements of water unite with the constituents of oxamide, and *ammonia* is one product formed, and *oxalic acid* the other, both in exactly the proper proportions to combine and form a neutral salt.

Here the contact of oxamide and oxalic acid induces a transformation of the oxamide, which is decomposed into oxalic acid and ammonia. The oxalic acid thus formed, as well as that originally added, are shared by the ammonia—or in other words, as much free oxalic acid exists after the decomposition as before it, and is of course still possessed of its original power. It matters not whether the free oxalic acid is that originally added, or that newly produced; it is certain that it has been reproduced in an equal quantity by the decomposition.

If we now add to the same mixture a fresh portion of oxamide, exactly equal in quantity to that first used, and treat it in the same manner, the same decomposition is repeated; the free oxalic acid enters into combination, whilst another portion is liberated. In this manner a very minute quantity of oxalic acid may be made to effect the decomposition of several hundred pounds of oxamide; and one grain of the acid to reproduce itself in unlimited quantity.

We know that the contact of the virus of small-pox causes such a change in the blood, as gives rise to the reproduction of the poison from the constituents of the fluid. This transformation is not arrested until all the particles of the blood which are susceptible of the decomposition have undergone the metamorphosis. We have just seen that the contact of oxalic acid with oxamide caused the production of fresh oxalic acid, which in its turn exercised the same action on a new portion of oxamide. The transformation was only arrested in consequence of the quantity of oxamide present being limited. In their form both these transformations belong to the same class. But no one except a person quite unaccustomed to view such changes will ascribe them to a vital power, although we admit they correspond remarkably to our common conceptions of life; they are really chemical processes dependent upon the common chemical forces.

Our notion of life involves something more than mere reproduction, namely, the idea of an active power exercised *by virtue of a definite form,* and production and generation *in a definite* form. By chemical agency we can produce the constituents of muscular fibre, skin, and hair; but we can form by their means no organized tissue, no organic cell.

The production of organs, the co-operation of a system of organs, and their power not only to produce their component parts from the food presented to them, but to generate *themselves* in their original form and with all their properties, are characters belonging exclusively to organic life, and constitute a form of reproduction independent of chemical powers.

The chemical forces are subject to the invisible cause by which this form is produced. Of the existence of this cause itself we are made aware only by the phenomena which it produces. Its laws must be investigated just as we investigate those of the other powers which affect motion and changes in matter.

The chemical forces are subordinate to this cause of life, just as they are to electricity, heat, mechanical motion, and friction. By the influence of the latter forces, they suffer changes in their direction, an increase or diminution of their intensity, or a complete cessation or reversal of their action.

Such an influence and no other is exercised by the vital principle over the chemical forces; but in every case where combination or decomposition takes place, chemical affinity and cohesion are in action

The vital principle is only known to us through the peculiar form of its instruments, that is, through the organs in which it resides. Hence, whatever kind of energy a a substance may possess, if it is amorphous and destitute of organs from which the impulse, motion or change proceeds, it does not live. Its energy depends in this case on a chemical action. Light, heat, electricity, or other influences may increase, diminish, or arrest this action, but they are not its efficient cause.

In the same way the vital principle governs the chemical powers in the living body. All those substances to which we apply the general name of food, and all the bodies formed from them in the organism, are chemical compounds. The vital principle has, therefore, no other resistance to overcome, in order to convert these substances into component parts of the organism, than the chemical powers by which their constituents are held together. If the food possessed life, not merely the chemical forces, but this vitality, would offer resistance to the vital force of the organism it nourished.

All substances adapted for assimilation are bodies of a very complex constitution; their atoms are highly complex, and are held together only by a weak chemical action. They are formed by the union of two or more simple compounds; and in proportion as the number of their atoms augments their disposition to enter into new combinations is diminished; that is, they lose the power of acting chemically upon other bodies.

Their complex nature, however, renders them more liable to be changed, by the agency of external causes, and thus to suffer decomposition. Any external agency, in many cases even mechanical friction, is sufficient to cause a disturbance in the equilibrium of the attraction of their constituents; they arrange themselves either into new, more simple, and permanent combinations, or if a foreign attraction exercise its influence upon it, they arrange themselves in accordance with that attraction.

The special characters of food, that is, of substances fitted for assimilation, are absence of active chemical properties, and the capability of yielding to transformations.

The equilibrium in the chemical attractions of the constituents of the food is disturbed by the vital principle, as we know it may be by many other causes. But the union of its elements, so as to produce new combinations and forms, indicates the presence of a peculiar mode of attraction, and the existence of a power distinct from all other powers of nature, namely, the vital principle.

All bodies of simple composition possess a greater or less disposition to form combinations. Thus oxalic acid is one of the simplest of the organic acids, while stearic acid is one of the most complex; and the former is the strongest, the latter one of the weakest, in respect to active chemical character. By virtue of this disposition, simple compounds produce changes in every body which offers no resistance to their action; they enter into combination and cause decomposition.

The vital principle opposes to the continual action of the atmosphere, moisture and temperature upon the organism, a resistance which is, in a certain degree, invincible. It is by the constant neutralization and renewal of these external influences that life and motion are maintained.

The greatest wonder in the living organism is the fact that an unfathomable wisdom has made the cause of a continual decomposition or destruction, namely, the support of the process of respiration, to be the means of renewing the organism, and of resisting all the other atmospheric influences, such as those of moisture and changes of temperature.

When a chemical compound of simple constitution is introduced into the stomach, or any other part of the organism, it must exercise a chemical action upon all substances with which it comes in contact; for we know the peculiar character of such a body to be an aptitude and power to enter into combinations and effect decompositions.

The chemical action of such a compound is of course opposed by the vital principle. The results produced depend upon the strength of their respective actions: either an equilibrium of both powers is attained, a change being effected without the destruction of the vital principle, in which case *a medicinal effect* is occasioned; or the acting body yields to the superior force of vitality, that is, *it is digested;* or lastly, the chemical action obtains the ascendency *and acts as a poison.*

Every substance may be considered as *nutriment,* which loses its former properties when acted on by the vital principle, and does not exercise a chemical action upon the living organ.

Another class of bodies change the direction, the strength, and intensity of the resisting force, (the vital principle,) and thus exert a modifying influence upon the functions of its organs. They produce a disturbance in the system, either by their presence, or by themselves undergoing a change; these are *medicaments.*

A third class of compounds are called *poisons,* when they possess the property of uniting with organs or with their component parts, and when their power of effecting this is stronger than the resistance offered by the vital principle.

The quantity of a substance and its condition must, obviously, completely change the mode of its chemical action.

Increase of quantity is known to be equivalent to superior affinity. Hence a *medicament* administered in excessive quantity may act as a *poison,* and a poison in small doses as a *medicament.*

Food will act as a poison, that is, it will produce disease, when it is able to exercise a chemical action by virtue of its quantity; or, when either its condition or its presence retards, prevents, or arrests the motion of any organ.

A compound acts as a poison when all the parts of an organ with which it is brought into contact enter into chemical combination with it, while it may operate as a medicine, when it produces only a partial change.

No other component part of the organism can be compared to the blood, in respect of the feeble resistance which it offers to exterior influences. The blood is not an organ which is formed, but an organ in the act of formation; indeed, it is the sum of all the organs which are being formed. The chemical force and the vital principle hold each other in such perfect equilibrium, that every disturbance, however trifling, or from whatever cause it may proceed, effects a change in the blood. This liquid possesses so little of permanence, that it cannot be removed from the body without immediately suffering a change, and cannot come in contact with any organ in the body, without yielding to its attraction.

The slightest action of a chemical agent upon the blood exercises an injurious influence; even the momentary contact with the air in the lungs, although effected through the medium of cells and membranes, alters the colour and other qualities of the blood. Every chemical action propagates itself through the mass of the blood; for example, the active chemical condition of the constituents of a body undergoing decomposition, fermentation, putrefaction, or decay, disturbs the equilibrium between the chemical force and the vital principle in the circulating fluid. Numerous modifications in the composition and condition of the compounds produced from the elements of the blood, result from the conflict of the vital force with the chemical affinity, in their incessant endeavour to overcome one another.

All the characters of the phenomena of contagion tend to disprove the existence of life in contagious matters. They without doubt exercise an influence very similar to some processes in the living organism; but the cause of this influence is chemical action, which is capable of being subdued by other chemical actions, by opposed agencies.

Several of the poisons generated in the body by disease lose all their power when introduced into the stomach, but others are not thus destroyed.

It is a fact very decisive of their chemical nature and mode of action, that those poisons which are neutral or alkaline, such as the poisonous matter of the contagious fever in cattle (*typhus contagiosus ruminantium,*) or that of the small-pox, lose their whole power of contagion in the stomach; whilst that of sausages, which has an acid reaction, retains all its frightful properties under the same circumstances.

In the former of these cases, the free acid present in the stomach destroys the action of the poison, the chemical properties of which are opposed to it; whilst in the latter it strengthens, or at all events does not offer any impediment to poisonous action.

Microscopical examination has detected peculiar bodies resembling the globules of the blood in malignant putrefying pus, in the matter of vaccine, &c. The presence of these bodies has given weight to the opinion, that contagion proceeds from the developement of a diseased organic life; and these formations have been regarded as the living seeds of disease.

This view, which is not adapted to discussion, has led those philosophers who are accustomed to search for explanations of phenomena in forms, to consider the yeast produced by the fermentation of beer as possessed of life. They have imagined it to be composed of animals or plants, which nourish themselves from the sugar in which they are placed, and at the same time yield alcohol and carbonic acid as excrementitious matters.[*]

It would perhaps appear wonderful if bodies, possessing a crystalline structure and geometrical figure, were formed during the processes of fermentation and putrefaction from the organic substances and tissues of organs. We know, on the contrary, that the complete dissolution into organic compounds is preceded by a series of transformations, in which the organic structures gradually resign their forms.

Blood, in a state of decomposition, may appear to the eye unchanged; and when we recognise the globules of blood in a liquid contagious matter, the utmost that we can thence infer is, that those globules have taken no part in the process of decomposition. All the phosphate of lime may be removed from bones, leaving them transparent and flexible like leather, without the form of the bones being in the smallest degree lost. Again, bones may be burned until they be quite white, and consist merely of a skeleton of phosphate of lime, but they will still possess their original form. In the same way processes of decomposition in the blood may affect individual constituents only of that fluid, which will become destroyed and disappear, whilst its other parts will maintain the original form.

Several kinds of contagion are propagated through the air: so that, according to the view already mentioned, we must ascribe life to a gas, that is, to an aeriform body.

All the supposed proofs of the vitality of contagions are merely ideas and figurative representations, fitted to render the phenomena more easy of apprehension by our senses, without explaining them. These figurative expressions, with which we are so willingly and easily satisfied in all sciences, are the foes of all inquiries into the mysteries of nature; they are like the ***fata morgana***, which show us deceitful views of seas, fertile fields, and luscious fruits, but leave us languishing when we have most need of what they promise.

It is certain that the action of contagions is the result of a peculiar influence dependent on chemical forces, and in no way connected with the vital principle. This influence is destroyed by chemical actions, and manifests itself wherever it is not subdued by some antagonist power. Its existence is recognised in a connected series of changes and transformations, in which it causes all substances capable of undergoing similar changes to participate.

An animal substance in the act of decomposition, or a substance generated from the component parts of a living body by disease, communicates its own condition to all parts of the system capable of entering into the same state, if no cause exist in these parts by which the change is counteracted or destroyed.

Disease is excited by contagion.

The transformations produced by the disease assume a series of forms.

In order to obtain a clear conception of these transformations, we may consider the changes which substances, more simply composed than the living body, suffer from the influence of similar causes. When putrefying blood or yeast in the act of transformation is placed in contact with a solution of sugar, the elements of the latter substance are transposed, so as to form alcohol and carbonic acid.

A piece of the rennet-stomach of a calf in a state of decomposition occasions the elements of sugar to assume a different arrangement. The sugar is converted into lactic acid without the addition or loss of any element. (1 atom of sugar of grapes $C_{12} H_{12} O_{12}$ yields two atoms of lactic acid$=2$ ($C_6 H_6 O_6$.)

When the juice of onions or of beet-root is made to ferment at high temperatures, lactic acid, mannite, and gum are formed. Thus, according to the different states of the transposition of the elements of the exciting body, the elements of the sugar arrange themselves in different manners, that is, different products are formed.

The immediate contact of the decomposing substance with the sugar is the cause by which its particles are made to assume new forms and natures. The removal of that substance occasions the cessation of the decomposition of the sugar, so that should its transformation be completed before the sugar, the latter can suffer no further change.

In none of these processes of decomposition is the exciting body reproduced; for the conditions necessary to its reproduction do not exist in the elements of the sugar.

Just as yeast, putrefying flesh, and the stomach of a calf in a state of decomposi-

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[*] Annalen der Pharmacie, Band xxix. S. 93 und 100.

tion, when introduced into solutions of sugar, effect the transformation of this substance, without being themselves regenerated; in the same manner, miasms and certain contagious matters produce diseases in the human organism, by communicating the state of decomposition of which they themselves are the subject, to certain parts of the organism, without themselves being reproduced in their peculiar form and nature during the progress of the decomposition.

The disease in this case is not *contagious.*

Now when yeast is introduced into a mixed liquid containing both sugar and gluten, such as wort, the act of decomposition of the sugar effects a change in the form and nature of the gluten, which is, in consequence, also subjected to transformation. As long as some of the fermenting sugar remains, gluten continues to be separated as yeast, and this new matter in its turn excites fermentation in a fresh solution of sugar or wort. If the sugar, however, should be first decomposed, the gluten which remains in solution is not converted into yeast. We see, therefore, that the reproduction of the exciting body here depends—

1. Upon the presence of that substance from which it was originally formed;

2. Upon the presence of a compound which is capable of being decomposed by contact with the exciting body.

If we express in the same terms the reproduction of contagious matter in contagious diseases, since it is quite certain that they must have their origin in the blood, we must admit that the blood of a healthy individual contains substances, by the decomposition of which the exciting body or contagion can be produced. It must further be admitted, when contagion results, that the blood contains a second constituent capable of being decomposed by the exciting body. It is only in consequence of the conversion of the second constituent, that the original exciting body can be reproduced.

A susceptibility of contagion indicates the presence of a certain quantity of this second body in the blood of a healthy individual. The susceptibility for the disease and its intensity must augment according to the quantity of that body present in the blood; and in proportion to its diminution or disappearance, the course of the disease will change.

When a quantity, however small, of contagious matter, that is of the exciting body, is introduced into the blood of a healthy individual, it will be again generated in the blood, just as yeast is reproduced from wort. Its condition of transformation will be communicated to a constituent of the blood; and in consequence of the transformation suffered by this substance, a body identical with or similar to the exciting or contagious matter will be produced from another constituent substance of the blood. The quantity of the exciting body newly produced must constantly augment, if its further transformation or decomposition proceeds more slowly than that of the compound in the blood, the decomposition of which it effects.

If the transformation of the yeast generated in the fermentation of wort proceeded with the same rapidity as that of the particles of the sugar contained in it, both would simultaneously disappear when the fermentation was completed. But yeast requires a much longer time for decomposition than sugar, so that after the latter has completely disappeared, there remains a much larger quantity of yeast than existed in the fluid at the commencement of the fermentation,—yeast which is still in a state of incessant progressive transformation, and therefore possessed of its peculiar property.

The state of change or decomposition which affects one particle of blood, is imparted to a second, a third, and at last to all the particles of blood in the whole body. It is communicated in like manner to the blood of another individual, to that of a third person, and so on—or in other words, the disease is excited in them also.

It is quite certain that a number of peculiar substances exist in the blood of some men and animals, which are absent from the blood of others.

The blood of the same individual contains, in childhood and youth, variable quantities of substances, which are absent from it in other stages of growth. The susceptibility of contagion by peculiar exciting bodies in childhood, indicates a propagation and regeneration of the exciting bodies, in consequence of the transformation of certain substances which are present in the blood, and in the absence of which no contagion could ensue. The form of a disease is termed *benignant,* when the tranformations are perfected on constituents of the body which are not essential to life, without the other parts taking a share in the decomposition; it is termed *malignant* when they affect essential organs.

It cannot be supposed that the different changes in the blood, by which its constituents are converted into fat, muscular fibre, substance of the brain and nerves, bones, hair, &c., and the transformation of food into blood, can take place without the simultaneous formation of new compounds which require to be removed from the body by the organs of excretion.

In an adult these excretions do not vary much either in their nature or quantity. The food taken is not employed in increasing the size of the body, but merely for the purpose of replacing any substances which may be consumed by the various actions in the organism; every motion, every manifestation of organic properties, and every organic action being attended by a change in the material of the body, and by the assumption of a new form by its constituents.[*]

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[*] The experiments of Barruel upon the different odours emitted from blood on the addition

But in a child this normal condition of sustenance is accompanied by an abnormal condition of growth and increase in the size of the body, and of each individual part of it. Hence there must be a much larger quantity of foreign substances, not belonging to the organism, diffused through every part of the blood in the body of a young individual.

When the organs of secretion are in proper action, these substances will be removed from the system; but when the functions of those organs are impeded, they will remain in the blood or become accumulated in particular parts of the body. The skin, lungs, and other organs, assume the functions of the diseased secreting organs, and the accumulated substances are eliminated by them. If, when thus exhaled, these substances happen to be in the state of progressive transformation, they are contagious; that is, they are able to produce the same state of disease in another healthy organism, provided the latter organism is susceptible of their action—or in other words, contains a matter capable of suffering the same process of decomposition.

The production of matters of this kind, which render the body susceptible of contagion, may be occasioned by the manner of living, or by the nutriment taken by an individual. A superabundance of strong and otherwise wholesome food may produce them, as well as a deficiency of nutriment, uncleanliness, or even the use of decayed substances as food.

All these conditions for contagion must be considered as accidental. Their formation and accumulation in the body may be prevented, and they may even be removed from it without disturbing its most important functions of health. Their presence is not necessary to life.

The action, as well as the generation of the matter of contagion is, according to this view, a chemical process participated in by all substances in the living body, and by all the constituents of those organs in which the vital principle does not overcome the chemical action. The contagion, accordingly, either spreads itself over every part of the body, or is confined particularly to certain organs, that is, the disease attacks all the organs or only a few of them, according to the feebleness or intensity of their resistance.

In the abstract chemical sense, reproduction of a contagion depends upon the presence of two substances, one of which becomes completely decomposed, but communicates its own state of transformation to the second. The second substance thus thrown into a state of decomposition is the newly-formed contagion.

The second substance must have been originally a constituent of the blood: the first may be a body accidentally present; but it may also be a matter necessary to life. If both be constituents indispensable for the support of the vital functions of certain principal organs, death is the consequence of their transformation. But if the absence of the one substance which was a constituent of the blood do not cause an immediate cessation of the functions of the most important organs, if they continue in their action, although in an abnormal condition, convalescence ensues. In this case the products of the transformations still existing in the blood are used for assimilation and at this period secretions of a peculiar nature are produced.

When the constituent removed from the blood is a product of an unnatural manner of living, or when its formation takes place only at a certain age, the susceptibility of contagion ceases upon its disappearance.

The effects of vaccine matter indicate that an accidental constitution of the blood is destroyed by a peculiar process of decomposition, which does not affect the other constituents of the circulating fluid.

If the manner in which the precipitated *yeast* of Bavarian beer acts (page 107) be called to mind, the modus operandi of vaccine lymph can scarcely be matter of doubt.

Both the kind of yeast here referred to and the ordinary ferment are formed from gluten, just as the vaccine virus and the matter of small pox are produced from the blood. Ordinary yeast and the virus of human small-pox, however, effect a violent tumultuous transformation, the former in vegetable juices, the latter in blood, in both of which fluids respectively their constituents are contained, and they are reproduced from these fluids with all their characteristic properties. The precipitated yeast of Bavarian beer on the other hand acts entirely upon the sugar of the fermenting liquid and occasions a very protracted decomposition of it, in which the gluten which is also present takes no part. But the air exercises an influence upon the latter substance, and causes it to assume a new form and nature, in consequence of which this kind of yeast also is reproduced.

The action of the virus of cow-pox is analogous to that of the low yeast; it communicates its own state of decomposition to a matter in the blood, and from a second matter is itself regenerated, but by a totally different mode of decomposition; the product possesses the mild form, and all the properties of the lymph of cow-pox.

The susceptibility of infection by the virus of human small-pox must cease after vaccination, for the substance to the presence of which this susceptibility is owing has been removed from the body by a peculiar process of decomposition artificially excited.

But this substance may be again generated in the same individual, so that he may again become liable to contagion, and a second or a third vaccination will again remove the peculiar substance from the system.

Chemical actions are propagated in no organs so easily as in the lungs, and it is well known that diseases of the lungs are above all others frequent and dangerous.

If it is assumed that chemical action and the vital principle mutually balance each other in the blood, it must farther be supposed that the chemical powers will have a certain degree of preponderance in the lungs, where the air and blood are in immediate contact; for these organs are fitted by nature to favour chemical action; they offer no resistance to the changes experienced by the venous blood.

The contact of air with venous blood is limited to a very short period of time by the motion of the heart, and any change beyond a determinate point is, in a certain degree, prevented by the rapid removal of the blood which has become arterialised. Any disturbance in the functions of the heart, and any chemical action from without, even though weak, occasions a change in the process of respiration. Solid substances also, such as dust from vegetable, animal, or inorganic bodies, act in the same way as they do in a saturated solution of a salt in the act of crystallization, that is, they occasion a deposition of solid matters from the blood, by which the action of the air upon the latter is altered or prevented.

When gaseous and decomposing substances, or those which exercise a chemical action, such as sulphuretted hydrogen and carbonic acid, obtain access to the lungs, they meet with less resistance in this organ than in any other. The chemical process of slow combustion in the lungs is accelerated by all substances in a state of decay or putrefaction, by ammonia and alkalies; but it is retarded by empyreumatic substances, volatile oils, and acids. Sulphuretted hydrogen produces immediate decomposition of the blood, and sulphurous acid combines with the substance of the tissues, the cells, and membranes.

When the process of respiration is modified by contact with a matter in the progress of decay, when this matter communicates the state of decomposition, of which it is the subject, to the blood, disease is produced.

If the matter undergoing decomposition is the product of a disease, it is called contagion; but if it is a product of the decay or putrefaction of animal and vegetable substances, or if it acts by its chemical properties, (not by the state in which it is,) and therefore enters into combination with parts of the body, or causes their decomposition, it is termed *miasm.*

Gaseous contagious matter is a miasm emitted from blood, and capable of generating itself again in blood

But miasm, properly so called, causes disease without being itself reproduced.

All the observations hitherto made upon gaseous contagious matters prove, that they also are substances in a state of decomposition. When vessels filled with ice are placed in air impregnated with gaseous contagious matter, their outer surfaces become covered with water containing a certain quantity of this matter in solution. This water soon becomes turbid, and in common language putrefies, or, to describe the change more correctly, the state of decomposition of the dissolved contagious matter is completed in the water.

All gases emitted from putrefying animal and vegetable substances in processes of disease, generally possess a peculiar nauseous offensive smell, a circumstance which, in most cases, proves the presence of a body in a state of decomposition. Smell itself may in many cases be considered as a reaction of the nerves of smell, or as a resistance offered by the vital powers to chemical action.

Many metals emit a peculiar odour when rubbed, but this is the case with none of the precious metals,—those which suffer no change when exposed to air and moisture. Arsenic, phosphorus, musk, the oils of linseed, lemons, turpentine, rue, and peppermint, possess an odour only when they are in the act of eremacausis (oxidation at common temperatures.)

The odour of gaseous contagious matters is owing to the same cause; but it is also generally accompanied by ammonia, which may be considered in many cases as the means through which the contagious matter receives a gaseous form, just as it is the means of causing the smell of innumerable substances of little volatility, and of many which have no odour. (Robiquet.)*

Ammonia is very generally produced in cases of disease; it is always emitted in those in which contagion is generated, and is an invariable product of the decomposition of animal matter. The presence of ammonia in the air of chambers in which diseased patients lie, particularly of those afflicted with a contagious disease, may be readily detected; for the moisture condensed by ice in the manner just described, produces a white precipitate in a solution of corrosive sublimate, just as a solution of ammonia does. The ammoniacal salts also, which are obtained by the evaporation of rainwater after an acid has been added, when treated with lime so as to set free their ammonia, emit an odour most closely resembling that of corpses, or the peculiar smell of dunghills.

By evaporating acids in air containing gaseous contagions, the ammonia is neutralised, and we thus prevent further decomposition, and destroy the power of the contagion, that is, its state of chemical

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of sulphuric acid, prove that peculiar substances are contained in the blood of different individuals; the blood of a man of a fair complexion and that of a man of dark complexion were found to yield different odours; the blood of animals also differed in this respect very perceptibly from that of man.

* Ann. de Chim. et de Phys. XV. 27.

change. Muriatic and acetic acids, and in several cases nitric acid, are to be preferred for this purpose before all others. Chlorine also is a substance which destroys ammonia and organic bodies with much facility; but it exerts such an injurious and prejudicial influence upon the lungs, that it may be classed amongst the most poisonous bodies known, and should never be employed in places in which men breathe.

Carbonic acid and sulphuretted hydrogen, which are frequently evolved from the earth in cellars, mines, wells, sewers, and other places, are amongst the most pernicious miasms. The former may be removed from the air by alkalies, the latter, by burning sulphur, (sulphurous acid,) or by the evaporation of nitric acid.

The characters of many organic compounds are well worthy of the attention and study both of physiologists and pathologists, more especially in relation to the mode of action of medicines and poisons.

Several of such compounds are known, which to all appearance are quite indifferent substances, and yet cannot be brought into contact with one another in water without suffering a complete transformation. All substances which thus suffer a mutual decomposition, possess complex atoms; they belong to the highest order of chemical compounds. For example, amygdalin, a constituent of bitter almonds, is a perfectly neutral body, of a slightly bitter taste, and very easily soluble in water. But when it is introduced into a watery solution of synaptas, (a constituent of sweet almonds,) it disappears completely without the disengagement of any gas, and the water is found to contain free hydrocyanic acid, hydruret of benzule (oil of bitter almonds,) a peculiar acid and sugar, all substances of which merely the elements existed in the amygdalin. The same decomposition is effected when bitter almonds, which contain the same white matter as the sweet, are rubbed into a powder and moistened with water. Hence it happens that bitter almonds pounded and digested in alcohol, yield no oil of bitter almonds containing hydrocyanic acid, by distillation with water; for the substance which occasions the formation of those volatile substances, is dissolved by alcohol without change, and is therefore extracted from the pounded almonds. Pounded bitter almonds contain no amygdalin, also, after having been moistened with water, for that substance is completely decomposed when they are thus treated.

No volatile compounds can be detected by their smell in the seeds of the *Sinapis alba* and *S. nigra.* A fixed oil of a mild taste is obtained from them by pressure, but no trace of a volatile substance. If, however, the seeds are rubbed to a fine powder, and subjected to distillation with water, a volatile oil of a very pungent taste and smell passes over along with the steam. But if, on the contrary, the seeds are treated with alcohol previously to their distillation with water, the residue does not yield a volatile oil. The alcohol contains a crystalline body called sinapin, and several other bodies. Those do not possess the characteristic pungency of the oil, but it is by the contact of them with water, and with the albuminous constituents of the seeds, that the volatile oil is formed.

Thus bodies regarded as absolutely indifferent in inorganic chemistry, on account of their possessing no prominent chemical characters, when placed in contact with one another, mutually decompose each other. Their constituents arrange themselves in a peculiar manner, so as to form new combinations; a complex atom dividing into two or more atoms of less complex constitution, in consequence of a mere disturbance in the attraction of their elements.

The white constituents of the almonds and mustard, which resemble coagulated albumen, must be in a peculiar state in order to exert their action upon amygdalin, and upon those constituents of mustard from which the volatile pungent oil is produced. If almonds, after being blanched and pounded, are thrown into boiling water, or treated with hot alcohol, with mineral acids, or with salts of mercury, their power to effect a decomposition in amygdalin is completely destroyed. Synaptas is an azotised body which cannot be preserved when dissolved in water. Its solution becomes rapidly turbid, deposits a white precipitate, and acquires the offensive smell of putrefying bodies.

It is exceedingly probable that the peculiar state of transposition into which the elements of synaptas are thrown when dissolved in water, may be the cause of the decomposition of amygdalin, and formation of the new products arising from it. The action of synaptas in this respect is very similar to that of rennet upon sugar.

Malt, and the germinating seeds of corn in general, contain a substance called *diastase,* which is formed from the gluten contained in them, and cannot be brought in contact with starch and water, without effecting a change in the starch.

When bruised malt is strewed upon warm starch made into a paste with water, the paste after a few minutes becomes quite liquid, and the water is found to contain, in place of starch, a substance in many respects similar to gum. But when more malt is added and the heat longer continued, the liquid acquires a sweet taste, and all the starch is found to be converted into sugar of grapes.

The elements of diastase have at the same time arranged themselves into new combinations.

The conversion of the starch contained in food into sugar of grapes in diabetes indicates that amongst the constituents of some one organ of the body a substance or substances exist in a state of chemical action, to which the vital principle of the diseased

organ opposes no resistance. The component parts of the organ must suffer changes simultaneously with the starch, so that the more starch is furnished to it, the more energetic and intense the disease must become; while if only food which is incapable of suffering such transformations from the same cause is supplied, and the vital energy is strengthened by stimulant remedies and nourishment, the chemical action may finally be subdued, or, in other words, the disease cured.

The conversion of starch into sugar may also be effected by pure gluten, and by dilute mineral acids.

From all the preceding facts, we see that very various transpositions, and changes of composition and properties, may be produced in complex organic molecules, by every cause which occasions a disturbance in the attraction of their elements.

When moist copper is exposed to air containing carbonic acid, the contact of this acid increases the affinity of the metal for the oxygen of the air in so great a degree that they combine, and the surface of the copper becomes covered with green carbonate of copper. Two bodies, which possess the power of combining together, assume, however, opposite electric conditions at the moment at which they come in contact.

When copper is placed in contact with iron, a peculiar electric condition is excited, in consequence of which the property of the copper to unite with oxygen is destroyed, and the metal remains quite bright.

When formate of ammonia is exposed to a temperature of 388° F. (180° C.) the intensity and direction of the chemical force undergo a change, and the conditions under which the elements of this compound are enabled to remain in the same form ceases to be present. The elements, therefore, arrange themselves in a new form; hydrocyanic acid and water being the result of the change.

Mechanical motion, friction, or agitation, is sufficient to cause a new disposition of the constituents of fulminating silver and mercury, that is, to effect another arrangement of their elements, in consequence of which, new compounds are formed.

We know that electricity and heat possess a decided influence upon the exercise of chemical affinity; and that the attractions of substances for one another are subordinate to numerous causes which change the condition of these substances, by altering the direction of their attractions. In the same manner, therefore, the exercise of chemical powers in the living organism is dependent upon the vital principle.

The power of elements to unite together, and to form peculiar compounds, which are generated in animals and vegetables, is chemical affinity; but the cause by which they are prevented from arranging themselves according to the degrees of their natural attractions—the cause, therefore, by which they are made to assume their peculiar order and form in the body—is the vital principle.

After the removal of the cause which forced their union—that is, after the extinction of life—most organic atoms retain their condition, form, and nature, only by a *vis inertiæ;* for a great law of nature proves that matter does not possess the power of spontaneous action. A body in motion loses its motion only when a resistance is opposed to it; and a body at rest cannot be put in motion, or into any action whatever, without the operation of some exterior cause.

The same numerous causes which are opposed to the formation of complex organic molecules, under ordinary circumstances, occasion their decomposition and transformations when the only antagonist power, the vital principle, no longer counteracts the influence of those causes. Contact with air and the most feeble chemical action now effect changes in the complex molecules; even the presence of any body the particles of which are undergoing motion or transposition, is often sufficient to destroy their state of rest, and to disturb the statical equilibrium in the attractions of their constituent elements. An immediate consequence of this is that they arrange themselves according to the different degrees of their mutual attractions, and that new compounds are formed in which chemical affinity has the ascendency, and opposes any further change, while the conditions under which these compounds were formed remained unaltered.

TABLES:

SHOWING THE PROPORTION BETWEEN THE HESSIAN AND ENGLISH STANDARD OF WEIGHTS AND MEASURES.

In general all the weights and measures employed in this edition are those of the English standard. In a few cases only, the Hessian weights and measures have been retained. In these the numbers do not represent absolute quantities, but are merely intended to denote a proportion to other numbers. This has been done to avoid any unnecessary intricacy in the calculations, and to present whole numbers to the reader, without distracting his attention by decimal parts. For those, however, who wish to be acquainted with the exact English quantities, a table is given below.

1 lb. English is equal to 0·90719 lbs. Hessian, hence, about one-tenth less than the latter.

1 lb. Hessian is equal to	1·102	lbs. English.
2 lbs. Hessian are equal to	2·204	"
3 - - - - -	3·306	"
4 - - - -	4·409	"
5 - - - - -	5·511	"
6 - - - - -	6·612	"
7 - - - - -	7·716	"
8 - - -	8·818	"

9 lbs. Hessian are equal to	9·92	lbs. English.
10	11·02	"
20	22·04	"
30	33·06	"
40	44·09	"
50	55·11	"
60	66·12	"
70	77·16	"
80	88·18	"
90	99·29	"
100	110·2	"
200	220·4	"
300	330·6	"
400	440·9	"
500	551·1	"
600	661·2	"
700	771·6	"
800	881·8	"
900	992·0	"
1000	1102·0	"

SQUARE FEET.

The Hessian acre is equal to 40,000 Hessian square feet, or 26,911 English square feet; 1 English square foot being equal to 1·4864 Hessian. The following is a table to save the trouble of calculation. The table is only stated to the figure 10, but by removing the decimal point one or two figures, the whole series given in the case of the pounds will also be obtained.

1 Sq. foot Hessian is equal to	0·612	Sq. foot Eng.
2 feet	1·345	"
3	2·018	feet
4	2·691	"
5	3·363	"
6	4·036	"
7	4·709	"
8	5·382	"
9	6·054	"
10	6·727	"

CUBIC FEET.

One English cubic foot contains 1·81218 of a Hessian cubic foot; the Hessian and English cubic inch may be considered as equal, one English cubic inch containing 1·048715 Hessian cubic inch.

1 cub. foot Hessian is eq. to	0·551	cub. foot Eng.
2 feet	1·103	"
3	1·665	feet
4	2·207	"
5	2·759	"
6	3·311	"
7	3·863	"
8	4·415	"
9	4·966	"
10	5·518	"

THE END.

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End of Volume

Volume:

2

ANIMAL CHEMISTRY,

OR

ORGANIC CHEMISTRY

IN ITS APPLICATIONS TO

PHYSIOLOGY AND PATHOLOGY.

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THE BRITISH ASSOCIATION
FOR
THE ADVANCEMENT OF SCIENCE.

At the meeting of the British Association in Glasgow, in 1840, I had the honour to present the first part of a report on the then present state of Organic Chemistry, in which I endeavoured to develope the doctrines of this science in their bearing on Agriculture and Physiology.

It affords me now much gratification to be able to communicate to the meeting of the Association for the present year the second part of my labours; in which I have attempted to trace the application of Organic Chemistry to Animal Physiology and Pathology.

In the present work an extensive series of phenomena have been treated in their chemical relations; and although it would be presumptuous to consider the questions here raised as being definitely resolved, yet those who are familiar with chemistry will perceive that the only method which can lead to their final resolution, namely, the *quantitative* method, has been employed.

The formulæ and equations in the second part, therefore, although they are not to be viewed as ascertained truths, and as furnishing a complete, or the only explanation of the vital processes there treated of, are yet true in this sense: that being deduced from facts by logical induction, they must stand as long as no new facts shall be opposed to them.

When the chemist shows, for example, that the elements of the bile, added to those of the urate of ammonia, correspond exactly to those of blood, he presents to us a fact which is independent of all hypothesis. It remains for the physiologist to determine, by experiment, whether the conclusions drawn by the chemist from such a fact be accurate or erroneous. And whether this question be answered in the affirmative or in the negative, the fact remains, and will some day find its true explanation.

I have now to perform the agreeable duty of expressing my sense of the services rendered to me in the preparation of the English edition by my friend, Dr. Gregory. The distinguished station he occupies as a chemist; the regular education which he has received in the various branches of medicine; and his intimate acquaintance with the German language—all these, taken together, are the best securities that the translation is such as to convey the exact sense of the original; securities, such as are not often united in the same individual.

It is my intention to follow this second part with a third, the completion of which, however, cannot be looked for before the lapse of two years. This third part will contain an investigation of the food of man and animals, the analysis of all articles of diet, and the study of the changes which the raw food undergoes in its preparation; as, for example, in fermentation (bread,) baking, roasting, boiling, &c. Already, it is true, many analyses have been made for the proposed work; but the number of objects of investigation is exceedingly large, and in order to determine with accuracy the absolute value of seed, or of flour, or of a species of fodder, &c., as food, the ultimate analysis alone is not sufficient; there are required comparative investigations, which present very great difficulties.

DR. JUSTUS LIEBIG.

Giessen, 3d *June*, 1852.

NOTE.

I **WOULD** beg leave to refer the chemical as well as the physiological reader particularly to the analyses (in Note (27) Appendix) of the animal tissues, which ought to have been referred to on pages 21 and 42, and which at present are only referred to in Note (7.) Since the work was printed, moreover, there has been added, at the end of the Appendix, an interesting paper by Keller (see page 101,) confirming the very important observation of A. Ure, junior, as to the conversion of benzoic acid into hippuric acid in the human body; a fact which, I perceive, by the Philosophical Magazine for June, has also been confirmed by Mr. Garrod, probably at an earlier period than by M. Keller. The reader will perceive that this fact strengthens materially the argument of the Author on the action of remedies.

W. G.

PREFACE.

By the application to chemistry of the methods which had for centuries been followed by philosophers in ascertaining the causes of natural phenomena in physics—by the observation of weight and measure—LAVOISIER laid the foundation of a new science, which, having been cultivated by a host of distinguished men, has, in a singularly short period, reached a high degree of perfection.

It was the investigation and determination of all the conditions which are essential to an observation or an experiment, and the discovery of the true principles of scientific research, that protected chemists from error, and conducted them, by a way equally simple and secure, to discoveries which have shed a brilliant light on those natural phenomena which were previously the most obscure and incomprehensible.

The most useful applications to the arts, to industry, and to all branches of knowledge related to chemistry, sprung from the laws thus established; and this influence was not delayed till chemistry had attained its highest perfection, but came into action with each new observation.

All existing experience and observation in other departments of science reacted, in like manner, on the improvement and development of chemistry; so that chemistry received from metallurgy and from other industrial arts as much benefit as she had conferred on them. While they simultaneously increased in wealth, they mutually contributed to the development of each other.

After mineral chemistry had gradually attained its present state of development, the labours of chemists took a new direction. From the study of the constituent parts of vegetables and animals, new and altered views have arisen; and the present work is an attempt to apply these views to physiology and pathology.

In earlier times the attempt has been made, and often with great success, to apply to the objects of the medical art the views derived from an acquaintance with chemical observations. Indeed, the great physicians, who lived towards the end of the seventeenth century, were the founders of chemistry, and in those days the only philosophers acquainted with it. The phlogistic system was the dawn of a new day; it was the victory of philosophy over the rudest empiricism.

With all its discoveries, modern chemistry has performed but slender services to physiology and pathology; and we cannot be deceived as to the cause of this failure, if we reflect that it was found impossible to trace any sort of relation between the observations made in inorganic chemistry, the knowledge of the characters of the elementary bodies and of such of their compounds as could be formed in the laboratory, on the one hand, and the living body, with the characters of its constituents, on the other.

Physiology took no share in the advancement of chemistry, because for a long period she received from the latter science no assistance in her own development. This state of matters has been entirely changed within five and twenty years. But during this period physiology has also acquired new ways and methods of investigation within her own province; and it is only the exhaustion of these sources of discovery which has enabled us to look forward to a change in the direction of the labours of physiologists. The time for such a change is now at hand; and a perseverance in the methods lately followed in physiology would now, from the want, which must soon be felt, of fresh points of departure for researches, render physiology more extensive, but neither more profound nor more solid.

No one will venture to maintain that the knowledge of the forms and of the phenomena of motion in organized beings is either unnecessary or unprofitable. On the contrary, this knowledge must be considered as altogether indispensable to that of the vital processes. But it embraces only one class of the conditions necessary for the acquisition of that knowledge, and is not of itself sufficient to enable us to attain it.

The study of the uses and functions of the different organs, and of their mutual connection in the animal body, was formerly the chief object of physiological researches; but lately this study has fallen into the back-ground. The greater part of all the modern discoveries has served to enrich comparative anatomy far more than physiology.

These researches have yielded the most valuable results in relation to the recognition of the dissimilar forms and conditions to be found in the healthy and in the diseased organism; but they have yielded no conclusions calculated to give us a more profound insight into the essence of the vital processes.

The most exact anatomical knowledge of the structure of the tissues cannot teach us their uses; and from the microscopical examination of the most minute reticulations of the vessels we can learn no more as to their functions than we have learned concerning vision from counting the surfaces on the eye of the fly. The most beautiful and elevated problem for the human intellect, the discovery of the laws of vitality, cannot be resolved, nay, cannot even be imagined, without an accurate knowledge of chemical forces; of those forces which do not act at sensible distances; which are manifested in the same way as those ultimate causes by which the vital phenomena are determined; and which are invariably found active, whenever dissimilar substances come into contact.

Physiology, even in the present day, still endeavours, but always after the fashion of the phlogistic chemists (that is, by the *qualitative* method,) to apply chemical experience to the removal of diseased conditions; but with all these countless experiments we are not one step nearer to the causes and the essence of disease.

With proposing well-defined questions, experimenters have placed blood, urine, and all the constituents of the healthy or diseased frame, in contact with acids, alkalies, and all sorts of chemical re-agents; and have drawn, from observation of the changes thus produced, conclusions as to their behaviour in the body.

By pursuing this method, useful remedies or modes of treatment might by accident be discovered; but a rational physiology cannot be founded on mere re-actions, and the living body cannot be viewed as a chemical laboratory.

In certain diseased conditions, in which the blood acquires a viscid consistence, this state cannot be permanently removed by a chemical action on the fluid circulating in the blood-vessels. The deposit of a sediment from the urine may perhaps, be prevented by alkalies, while their action has not the remotest tendency to remove the cause of disease. Again, when we observe, in typhus, insoluble salts of ammonia in the fæces, and a change in the globules of the blood similar to that which may be artificially produced by ammonia, we are not, on that account, entitled to consider the presence of ammonia in the body as the cause, but only as the effect of a cause.

Thus medicine, after the fashion of the Aristotelian philosophy, has formed certain conceptions in regard to nutrition and sanguification; articles of diet have been divided into nutritious and non-nutritious; but these theories, being founded on observations destitute of the conditions most essential to the drawing of just conclusions, could not be received as expressions of the truth.

How clear are now to us the relations of the different articles of food to the objects which they serve in the body, since organic chemistry has applied to the investigation her *quantitative method* of research!

When a lean goose, weighing 4 lbs., gains, in thirty-six days, during which it has been fed with 24 lbs. of maize, 5 lbs. in weight and yields 3½ lbs. of pure fat, this fat cannot have been contained in the food, ready formed, because maize does not contain the thousandth part of its weight of fat, or of any substance resembling fat. And when a certain number of bees, the weight of which is exactly known, being fed with pure honey, devoid of wax, yield one part of wax for every twenty parts of honey consumed, without any change being perceptible in their health or in their weight, it is impossible any longer to entertain doubt as to the formation of fat from sugar in the animal body.

We must adopt the method which has thus led to the discovery of the origin of fat, in the investigation of the origin and alteration of the secretions, as well as in the study of all the other phenomena of the animal body. From the moment that we begin to look earnestly and conscientiously for the true answers to our questions, that we take the trouble, by means of weight and measure, to fix our observations, and express them in the form of equations, these answers are obtained without difficulty.

However numerous our observations may be, yet, if they only bear on one side of a question, they will never enable us to penetrate the essence of a natural phenomenon in its full significance. If we are to derive any advantage from them, they must be directed to a well defined object; and there must be an organized connection between them.

Mechanical philosophers and chemists justly ascribe to their methods of research the greater part of the success which has attended their labours. The result of every such investigation, if it bear in any degree the stamp of perfection, may always be given in few words; but these few words are eternal truths, to the discovery of which numberless experiments and questions were essential. The researches themselves, the laborious experiments and complicated apparatus, are forgotten as soon as the truth is ascertained. They were the ladders, the shafts, the tools, which were indispensable to enable us to attain to the rich vein of ore; they were the pillars and air passages which protected the mine from water and from foul air.

Every chemical or physical investigation, however insignificant, which lays claim to attention, must in the present day possess this character. From a certain number of observations it must enable us to draw some conclusion, whether it be extended or limited.

The imperfection of the method or system of research adopted by physiologists can alone explain the fact, that for the last fifty years they have established so few new and solid truths in regard to a more profound knowledge of the functions of the most important organs, of the spleen, of the liver, and of the numerous glands of the body; and the limited acquaintance of physiologists with the methods of research employed in chemistry will continue to be the chief impediment to the progress of physiology, as well as a reproach which that science cannot escape.

Before the time of Lavoisier, Scheele, and Priestley, chemistry was not more closely related to physics than she is now to physiology. At the present day chemistry is so fused, as it were, into physics, that it would be a difficult matter to draw the line between them distinctly. The connection between chemistry and physiology is the same, and in another half century it will be found impossible to separate them.

Our questions and our experiments intersect in numberless curved lines the straight line that leads to truth. It is the points of intersection that indicate to us the true direction; but, owing to the imperfection of the human intellect, these curve lines must be pursued. Observers in chemistry and physics have the eye ever fixed on the object which they seek to attain. One may succeed, for a space, in following the direct line; but all are prepared for circuitous paths. Never doubting of the ultimate success of their efforts, provided they exhibit constancy and perseverance, their eagerness and courage are only exalted by difficulties.

Detached observations, without connection, are points scattered over the plain, which do not allow us to choose a decided path. For centuries chemistry presented nothing but these points, and sufficient means were available to fill up the intervals between them. But permanent discoveries and real progress were only made when chemists ceased to make use of fancy to connect them.

My object in the present work has been to direct attention to the points of intersection of chemistry with physiology, and to point out those parts in which the sciences become, as it were, mixed up together. It contains a collection of problems, such as chemistry at present requires to be resolved; and a number of conclusions drawn according to the rules of that science from such observations as have been made.

These questions and problems will be resolved: and we cannot doubt that we shall have in that case a new physiology and a rational pathology. Our sounding line, indeed, is not long enough to measure the depths of the sea, but is not on that account less valuable to us: if it assist us, in the mean time, to avoid rocks and shoals, its use is sufficiently obvious. In the hands of the physiologist, organic chemistry must become an intellectual instrument, by means of which he will be enabled to trace the causes of phenomena invisible to the bodily sight; and if among the results which I have developed or indicated in this work, one alone shall admit of a useful application, I shall consider the object for which it was written as fully attained. The path which has led to it will open up other paths; and this I consider as the most important object to be gained.

JUSTUS LIEBIG.

Giessen, April, 1852.

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ORGANIC CHEMISTRY
APPLIED TO
PHYSIOLOGY AND PATHOLOGY.

I. In the animal ovum, as well as in the seed of a plant, we recognise a certain remarkable force, the source of growth, or increase in the mass, and of reproduction, or of supply of the matter consumed; a force in a state of rest. By the action of external influences, by impregnation, by the presence of air and moisture, the condition of static equilibrium of this force is disturbed; entering into a state of motion or activity, it exhibits itself in the production of a series of forms, which, although occasionally bounded by right lines, are yet widely distinct from geometrical forms, such as we observe in crystallised minerals. This force is called the ***vital force***, or ***viz vitæ vitality***.

The increase of mass in a plant is determined by the occurrence of a decomposition which takes place in certain parts of the plant under the influence of light and heat.

In the vital process, as it goes on in vegetables, it is exclusively inorganic matter which undergoes this decomposition; and if, with the most distinguished mineralogists, we consider atmospherical air and certain other gases as minerals, it may be said that the vital process in vegetables accomplishes the transformation of mineral substances into an organism endued with life; that the mineral becomes part of an organ possessing vital force.

The increase of mass in a living plant implies that certain component parts of its nourishment become component parts of the plant; and a comparison of the chemical composition of the plant with that of its nourishment, makes known to us, with positive certainty, which of the component parts of the latter have been assimilated, and which have been rejected.

The observations of vegetable physiologists and the researches of chemists have mutually contributed to establish the fact, that the growth and development of vegetables depend on the elimination of oxygen, which is separated from the other component parts of their nourishment.

In contradiction to vegetable life, the life of animals exhibits itself in the continual absorption of the oxygen of the air, and its combination with certain component parts of the animal body

While no part of an organized being can serve as food to vegetables, until, by the processes of putrefaction and decay, it has assumed the form of inorganic matter, the animal organism requires, for its support and development, highly organized atoms. The food of all animals, in all circumstances, consists of parts of organisms.

Animals are distinguished from vegetables by the faculty of locomotion, and, in general, by the possession of senses.

The existence and activity of these distinguishing faculties depend on certain instruments which are never found in vegetables. Comparative anatomy shows, that the phenomena of motion and sensation depend on certain kinds of apparatus, which have no other relation to each other than this, that they meet in a common centre. The substance of the spinal marrow, the nerves, and the brain, is in its composition, and in its chemical characters, essentially distinct from that of which cellular substance, membranes, muscles, and skin are composed.

Every thing in the animal organism, to which the name of *motion* can be applied, proceeds from the nervous apparatus. The phenomena of motion in vegetables, the circulation of the sap, for example, observed in many of the characeæ, and the closing of flowers and leaves, depend on physical and mechanical causes. A plant is destitute of nerves. Heat and light are the remote causes of motion in vegetables; but in animals we recognise in the nervous apparatus a source of power, capable of renewing itself at every moment of their existence.

While the assimilation of food in vegetables, and the whole process of their formation, are dependant on certain external influences which produce motion, the development of the animal organism is, to a certain extent, independent of these external influences, just because the animal body can produce within itself that source of motion which is indispensable to the vital process.

Assimilation, or the process of formation and growth—in other words, the passage of matter from a state of motion to that of rest—goes on in the same way in animals and in vegetables. In both, the same cause determines the increase of mass. This constitutes the true vegetative life, which is carried on without consciousness.

The activity of vegetative life manifests itself, in vegetables, with the aid of external influences; in animals, by means of influences produced within their organism. Digestion, circulation, secretion, are no doubt under the influence of the nervous system; but the force which gives to the germ, the leaf, and the radical fibres of the vegetable the same wonderful properties, is the same as that residing in the secreting membranes and glands of animals, and which enables every animal organ to perform its own proper function. It is only the source of motion that differs in the two great classes of organized beings.

While the organs of the vital motions are never wanting in the lowest orders of animals, as in the impregnated germ of the ovum, in which they are developed first of all, we find, in the higher orders of animals, peculiar organs of feeling and sensation, of consciousness and of a higher intellectual existence.

Pathology informs us that the true vegetative life is in no way dependant on the presence of this apparatus; that the process of nutrition proceeds in those parts of the body where the nerves of sensation and voluntary motion are paralysed, exactly in the same way as in other parts where these nerves are in the normal condition; and, on the other hand, that the most energetic volition is incapable of exerting any influence on the contractions of the heart, on the motion of the intestines, or on the processes of secretion.

The higher phenomena of mental existence cannot, in the present state of science, be referred to their proximate, and still less to their ultimate causes. We only know of them, that they exist; we ascribe them to an immaterial agency, and that, in so far as its manifestations are connected with matter, an agency entirely distinct from the vital force, with which it has nothing in common.

It cannot be denied that this peculiar force exercises a certain influence on the activity of vegetative life, just as other immaterial agents, such as Light, Heat, Electricity, and Magnetism do; but this influence is not of a determinative kind, and manifests itself only as an acceleration, a retarding, or a disturbance of the process of vegetative life. In a manner exactly analogous, the vegetative life re-acts on the conscious mental existence.

There are thus two forces which are found in activity together; but consciousness and intellect may be absent in animals as they are in living vegetables, without their vitality being otherwise affected than by the want of a peculiar source of increased energy or of disturbance. Except in regard to this, all the vital chemical processes go on precisely in the same way in man and in the lower animals.

The efforts of philosophers, constantly renewed, to penetrate the relations of the soul to animal life, have all along retarded the progress of physiology. In this attempt men left the province of philosophical research for that of fancy; physiologists, carried away by imagination, were far from being acquainted with the laws of purely animal life. None of them had a clear conception of the process of development and nutrition, or of the true cause of death. They professed to explain the most obscure psychological phenomena, and yet they were unable to say what fever is, and in what way quinine acts in curing it.

For the purpose of investigating the laws of vital motion in the animal body, only one condition, namely, the knowledge of the apparatus which serves for its production, was ascertained; but the substance of the organs, the changes which food undergoes in the living body, its transformation into portions of organs, and its reconversion into lifeless compounds, the share which the atmosphere takes in the processes of vitality; all these foundations for future conclusions were still wanting.

What has the soul, what have consciousness and intellect to do with the development of the human fœtus, or the fœtus in a fowl's egg? not more, surely, than with the development of the seeds of a plant. Let us first endeavour to refer to their ultimate causes those phenomena of life which are not physiological; and let us beware of drawing conclusions before we have a groundwork. We know exactly the mechanism of the eye; but neither anatomy nor chemistry will ever explain how the rays of light act on consciousness, so as to produce vision. Natural science has fixed limits which cannot be passed; and it must always be borne in mind that, with all our discoveries, we shall never know what light, electricity, and magnetism are in their essence, because, even of those things which are material, the human intellect has only conceptions. We can ascertain, however, the laws which regulate their motion and rest, because these are manifested in phenomena. In like manner the laws of vitality, and of all that disturbs, promotes, or alters it, may certainly be discovered, although we shall never learn what life is. Thus the discovery of the laws of gravitation and of the planetary motions led to an entirely new conception of the cause of these phenomena. This conception could not have been formed in all its clearness without a knowledge of phenomena out of which it was evolved; for, considered by itself, gravity, like light to one born blind, is a mere word, devoid of meaning.

The modern science of physiology has left the track of Aristotle. To the eternal advantage of science, and to the benefit of mankind, it no longer invents a *horror vacui*, a *quinta essentia*, in order to furnish credulous hearers with solutions and explanations of phenomena, whose true connection with others, whose ultimate cause is still unknown.

If we assume that all the phenomena exhibited by the organism of plants and animals are to be ascribed to a peculiar cause, different in its manifestations from all other causes which produce motion or change of condition; if, therefore, we regard the vital force as an independent force, then, in the phenomena of organic life, as in all other phenomena ascribed to the action of forces, we have the *statics*, that is, the state of equilibrium determined by a resistance, and the *dynamics*, of the vital force.

All the parts of the animal body are produced from a peculiar fluid, circulating in its organism, by virtue of an influence residing in every cell, in every organ, or part of an organ. Physiology teaches that all parts of the body were originally blood; or that at least they were brought to the growing organs by means of this fluid.

The most ordinary experience farther shows, that at each moment of life, in the animal organism, a continued change of matter, more or less accelerated, is going on; that a part of the structure is transformed into unorganized matter, loses its condition of life, and must be again renewed. Physiology has sufficiently decisive grounds for the opinion, that every motion, every manifestation of force, is the result of a transformation of the structure or of its substance; that every conception, every mental affection, is followed by changes in the chemical nature of the secreted fluids; that every thought, every sensation, is accompanied by a change in the composition of the substance of the brain.

In order to keep up the phenomena of life in animals, certain matters are required, parts of organisms, which we call nourishment. In consequence of a series of alterations, they serve either for the increase of the mass (*nutrition*,) or for the supply of the matter consumed (*reproduction*,) or, finally, for the production of force.

II. If the first condition of animal life be the assimilation of what is commonly called nourishment, the second is a continual absorption of oxygen from the atmosphere.

Viewed as an object of scientific research, animal life exhibits itself in a series of phenomena, the connection and recurrence of which are determined by the changes which the food and the oxygen absorbed from the atmosphere undergo in the organism under the influence of the vital force.

All vital activity arises from the mutual action of the oxygen of the atmosphere and the elements of the food.

In the processes of nutrition and reproduction, we perceive the passage of matter from the state of motion to that of rest (static equilibrium;) under the influence of the nervous system, this matter enters again into a state of motion. The ultimate causes of these different conditions of the vital force are chemical forces.

The cause of the state of rest is a resistance, determined by a force of attraction (combination,) which acts between the smallest particles of matter, and is manifested only when these are in actual contact, or at infinitely small distances.

To this peculiar kind of attraction we may of course apply different names; but the chemist calls it *affinity*.

The cause of the state of motion is to be found in a series of changes which the food undergoes in the organism, and these are the results of processes of decomposition, to which either the food itself, or the structures formed from it, or parts of organs, are subjected.

The distinguishing character of vegetable life is a continued passage of matter from the state of motion to that of static equilibrium. While a plant lives, we cannot perceive any cessation in its growth; no part of an organ in the plant diminishes in size. If decomposition occur, it is the result of assimilation. A plant produces within itself no cause of motion; no part of its structure, from any influence residing in its organism, loses its state of vitality, and is converted into unorganized, amorphous compounds; in a word, no waste occurs in vegetables. Waste, in the animal body, is a change in the state or in the composition of some of its parts, and consequently is the result of chemical actions.

The influence of poisons and of remedial agents on the living animal body evidently shows that the chemical decompositions and combinations in the body, which manifest themselves in the phenomena of vitality, may be increased in intensity by chemical forces of analogous character, and retarded or put an end to by those of opposite character; and that we are enabled to exercise an influence on every part of an organ by means of substances possessing a well-defined chemical action.

As, in the closed galvanic circuit, in consequence of certain changes which an inorganic body, a metal, undergoes when placed in contact with an acid, a certain something becomes cognizable by our senses, which we call a current of electricity; so, in the animal body, in consequence of transformations and changes undergone by matter previously constituting a part of the organism, certain phenomena of motion and activity are perceived, and these we call life, or vitality.

The electrical current manifests itself in certain phenomena of attraction and repulsion, which it excites in other bodies naturally motionless, and by the phenomena of the formation and decomposition of chemical compounds, which occur every where, when the resistance is not sufficient to arrest the current.

It is from this point of view, and from no other, that chemistry ought to contemplate the phenomena of life. Wonders surround us on every side. The formation of a crystal, of an octahedron, is not less incomprehensible than the production of a leaf or of a muscular fibre; and the production of vermilion from mercury and sulphur is as much an enigma as the formation of an eye from the substance of the blood.

The first conditions of animal life are nutritious matters and oxygen, introduced into the system.

At every moment of his life man is taking oxygen into his system, by means of the organs of respiration; no pause is observable while life continues.

The observations of physiologists have shown that the body of an adult man, supplied with sufficient food, has neither increased nor diminished in weight at the end of twenty-four hours; yet the quantity of oxygen taken into the system during this period is very considerable.

According to the experiments of Lavoisier, an adult man takes into his system, from the atmosphere, in one year, 746 lbs., according to Menzies, 837 lbs. of oxygen; yet we find his weight, at the beginning and end of the year, either quite the same, or differing, one way or the other, by at most a few pounds. (1)[*]

What, it may be asked, has become of the enormous weight of oxygen thus introduced, in the course of a year into the human system?

This question may be answered satisfactorily; no part of this oxygen remains in the system; but it is given out again in the form of a compound of carbon or of hydrogen.

The carbon and hydrogen of certain parts of the body have entered into combination with the oxygen introduced through the lungs and through the skin, and have been given out in the forms of carbonic acid gas and the vapour of water.

At every moment, with every expiration, certain quantities of its elements separate from the animal organism, after having entered into combination, within the body, with the oxygen of the atmosphere.

If we assume, with Lavoisier and Seguin, in order to obtain a foundation for our calculation, that an adult man receives into his system daily $32\frac{1}{2}$oz. (46,037 cubic inches= 15,661 grains, French weight) of oxygen, and that the weight of the whole mass of his blood, of which 80 per cent. is water, is 24 lbs.; it then appears, from the known composition of the blood, that, in order to convert the whole of its carbon and hydrogen into carbonic acid and water, 64,103 grains of oxygen are required. This quantity will be taken into the system of an adult in four days five hours. (2)

Whether this oxygen enters into combination with the elements of the blood, or with other parts of the body containing carbon and hydrogen, in either case the conclusion is inevitable, that the body of a man who daily takes into the system $32\frac{1}{2}$ oz. of oxygen, must receive daily in the shape of nourishment, as much carbon and hydrogen as would suffice to supply 24 lbs. of blood with these elements; it being presupposed that the weight of the body remains unchanged, and that it retains its normal condition as to health.

This supply is furnished in the food.

From the accurate determination of the quantity of carbon daily taken into the system in the food, as well as of that proportion of it which passes out of the body in the fæces and urine, unburned, that is, in some form in which it is not combined with oxygen, it appears that an adult, taking moderate exercise, consumes 13.9 oz. of carbon daily. (3)

These $13\frac{9}{10}$ oz. of carbon escape through the skin and lungs as carbonic acid gas.

For conversion into carbonic acid gas, $13\frac{9}{10}$ oz. of carbon require 37 oz. of oxygen.

According to the analyses of Boussingault (Ann. de Ch. et de Ph. LXXI. p. 136) a horse consumes in twenty-four hours $97\frac{1}{8}$ oz. of carbon, a milk cow $69\frac{9}{10}$ oz. The quantities of carbon here mentioned are those given off from the bodies of these animals in the form of carbonic acid; and it appears from them that the horse consumes, in converting carbon into carbonic acid, 13 lbs. $3\frac{1}{2}$ oz. in twenty-four hours, and the milk cow 11 lbs. $10\frac{3}{4}$ oz. of oxygen in the same time. (4)

Since no part of the oxygen taken into the system is again given off in any other form but that of a compound of carbon or hydrogen; since, farther, the carbon and hydrogen given off are replaced by carbon and hydrogen supplied in the food, it is clear that the amount of nourishment required by the animal body must be in a direct ratio to the quantity of oxygen taken into the system.

Two animals, which in equal times take up by means of the lungs and skin unequal quantities of oxygen, consume quantities of the same nourishment which are unequal in the same ratio.

The consumption of oxygen in equal times may be expressed by the number of respirations; it is clear that, in the same individual, the quantity of nourishment required must vary with the force and number of the respirations.

A child, in whom the organs of respiration are naturally very active, requires food oftener than an adult, and bears hunger less easily. A bird, deprived of food, dies on the third day, while a serpent, with its sluggish respiration, can live without food three months and longer.

The number of respirations is smaller in a state of rest than during exercise or work. The quantity of food necessary in both conditions must vary in the same ratio.

An excess of food is incompatible with deficiency in respired oxygen, that is, with deficient exercise; just as violent exercise, which implies an increased supply of food, is incompatible with weak digestive organs. In either case the health suffers.

But the quantity of oxygen inspired is also affected by the temperature and density of the atmosphere.

The capacity of the chest in an animal is a constant quantity. At every respiration a quantity of air enters, the volume of which may be considered as uniform; but its weight, and consequently that of the oxygen it contains, is not constant. Air is expanded by heat, and contracted by cold, and therefore equal volumes of hot and cold air contain unequal weights of oxygen. In summer, moreover, atmospherical air contains aqueous vapour, while in winter it is dry; the space occupied by vapour in the warm air is filled up by air itself in winter; that is, it contains, for the same volume, more oxygen in winter than in summer.

In summer and in winter, at the pole and at the equator, we respire an equal volume of air; the cold air is warmed during respiration, and acquires the temperature of the body. To introduce into the lungs a given volume of oxygen, less expenditure of force is necessary in winter than in summer; and for the same expenditure of force, more oxygen is inspired in winter.

It is obvious, that in an equal number of respirations we consume more oxygen at the level of the sea than on a mountain. The quantity both of oxygen inspired and of carbonic acid expired, must, therefore, vary with the height of the barometer.

The oxygen taken into the system is given out again in the same forms, whether in summer or in winter; hence we expire more carbon in cold weather, and when the barometer is high, than we do in warm weather; and we must consume more or less carbon in our food in the same proportion; in Sweden more than in Sicily; and in our more temperate climate a full eighth more in winter than in summer.

Even when we consume equal weights of food in cold and warm countries, infinite wisdom has so arranged, that the articles of food in different climates are most unequal in the proportion of carbon they contain. The fruits on which the natives of the south prefer to feed do not in the fresh state contain more than 12 per cent. of carbon, while the bacon and train oil used by the inhabitants of the arctic regions contain from 66 to 80 per cent. of carbon.

It is no difficult matter, in warm climates, to study moderation in eating, and men can bear hunger for a long time under the equator; but cold and hunger united very soon exhaust the body.

The mutual action between the elements of the food and the oxygen conveyed by the circulation of the blood to every part of the body is THE SOURCE OF ANIMAL HEAT.

III. All living creatures, whose existence depends on the absorption of oxygen, possess within themselves a source of heat independent of surrounding objects.

This truth applies to all animals, and extends, besides, to the germination of seeds, to the flowering of plants, and to the maturation of fruits.

It is only in those parts of the body to which arterial blood, and with it the oxygen absorbed in respiration, is conveyed, that heat is produced. Hair, wool, or feathers, do not possess an elevated temperature.

This high temperature of the animal body, or, as it may be called, disengagement of heat, is uniformly and under all circumstances the result of the combination of a combustible substance with oxygen.

In whatever way carbon may combine with oxygen, the act of combination cannot take place without the disengagement of heat. It is a matter of indifference whether the combination take place rapidly or slowly, at a high or at a low temperature; the amount of heat liberated is a constant quantity.

The carbon of the food, which is converted into carbonic acid within the body, must give out exactly as much heat as if it had been directly burnt in the air or in oxygen gas; the only difference is, that the amount of heat produced is diffused over unequal times. In oxygen, the combustion is more rapid, and the heat more intense; in air it is slower, the temperature is not so high, but it continues longer.

It is obvious that the amount of heat liberated must increase or diminish with the quantity of oxygen introduced in equal times by respiration. Those animals which respire frequently, and consequently, consume much oxygen, possess a higher temperature than others, which, with a body of equal size to be heated, take into the system less oxygen. The temperature of a child (102°) is higher than that of an adult (99·5°). That of birds (104° to 105·4°) is higher than that of quadrupeds (98·5° to 100·4°) or than that of fishes or amphibia, whose proper temperature is from 2·7° to 3·6° higher than that of the medium in which they live. All animals, strictly speaking are warm-blooded; but in those only which possess lungs is the temperature of the body quite independent of the surrounding medium. (5)

The most trustworthy observations prove that in all climates, in the temperate zones as well as at the equator or the poles, the temperature of the body in man, and in what are commonly called warm-blooded animals, is invariably the same; yet how different are the circumstances under which they live!

The animal body is a heated mass, which bears the same relation to surrounding objects as any other heated mass. It receives heat when the surrounding objects are hotter, it loses heat when they are colder than itself.

We know that the rapidity of cooling in

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[*] The Numbers refer to the Appendix.

creases with the difference between the temperature of the heated body and that of the surrounding medium; that is, the colder the surrounding medium the shorter the time required for the cooling of the heated body.

How unequal, then, must be the loss of heat in a man at Palermo, where the external temperature is nearly equal to that of the body, and in the polar regions, where the external temperature is from 70° to 90° lower.

Yet, notwithstanding this extremely unequal loss of heat, experience has shown that the blood of the inhabitant of the arctic circle has a temperature as high as that of the native of the south, who lives in so different a medium.

This fact, when its true significance is perceived, proves that the heat given off to the surrounding medium is restored within the body with great rapidity. This compensation takes place more rapidly in winter than in summer, at the pole than at the equator.

Now, in different climates the quantity of oxygen introduced into the system of respiration, as has been already shown, varies according to the temperature of the external air; the quantity of inspired oxygen increases with the loss of heat by external cooling, and the quantity of carbon or hydrogen necessary to combine with this oxygen must be increased in the same ratio.

It is evident that the supply of the heat lost by cooling is effected by the mutual action of the elements of the food and the inspired oxygen, which combine together. To make use of a familiar, but not on that account a less just illustration, the animal body acts, in this respect, as a furnace, which we supply with fuel. It signifies nothing what intermediate forms food may assume, what changes it may undergo in the body, the last change is uniformly the conversion of its carbon into carbonic acid, and of its hydrogen into water; the unassimilated nitrogen of the food, along with the unburned or unoxidised carbon, is expelled in the urine or in the solid excrements. In order to keep up in the furnace a constant temperature, we must vary the supply of fuel according to the external temperature, that is, according to the supply of oxygen.

In the animal body the food is the fuel; with a proper supply of oxygen we obtain the heat given out during its oxidation or combustion. In winter, when we take exercise in a cold atmosphere, and when consequently, the amount of inspired oxygen increases, the necessity for food containing carbon and hydrogen increases in the same ratio; and by gratifying the appetite thus excited, we obtain the most efficient protection against the most piercing cold. A starving man is soon frozen to death; and every one knows that the animals of prey in the arctic regions far exceed in voracity those of the torrid zone.

In cold and temperate climates, the air, which incessantly strives to consume the body, urges man to labourious efforts in order to furnish the means of resistance to its action, while, in hot climates, the necessity of labour to provide food is far less urgent.

Our clothing is merely an equivalent for a certain amount of food. The more warmly we are clothed the less urgent becomes the appetite for food, because the loss of heat by cooling, and consequently the amount of heat to be supplied by the food, is diminished.

If we were to go naked, like certain savage tribes, or if in hunting or fishing we were exposed to the same degree of cold as the Samoyedes, we should be able with ease to consume 10 lbs. of flesh, and perhaps, a dozen of tallow candles into the bargain, daily, as warmly clad travellers have related with astonishment of these people! We should, then, also be able to take the same quantity of brandy or train oil without bad effects, because the carbon and hydrogen of these substances would only suffice to keep up the equilibrium between the external temperature and that of our bodies.

According to the preceding expositions, the quantity of food is regulated by the number of respirations, by the temperature of the air, and by the amount of heat given off to the surrounding medium.

No isolated fact, apparently opposed to this statement, can affect the truth of this natural law. Without temporary or permanent injury to health, the Neapolitan cannot take more carbon and hydrogen in the shape of food than he expires as carbonic acid and water; and the Esquimaux cannot expire more carbon and hydrogen than he takes into the system as food, unless in a state of disease or of starvation. Let us examine these states a little more closely.

The Englishman in Jamaica sees with regret the disappearance of his appetite, previously a source of frequently recurring enjoyment; and he succeeds by the use of cayenne pepper and the most powerful stimulants, in enabling himself to take as much food as he was accustomed to eat at home. But the whole of the carbon thus introduced into the system is not consumed; the temperature of the air is too high, and the oppressive heat does not allow him to increase the number of respirations by active exercise, and thus to proportion the waste to the amount of food taken; disease of some kind, therefore, ensues.

On the other hand, England sends her sick, whose diseased digestive organs have in a greater or less degree lost the power of bringing the food into that state in which it is best adapted for oxidation, and therefore, furnish less resistance to the oxidising agency of the atmosphere than is required in their native climate, to southern regions where the amount of inspired oxygen is diminished in so great a proportion; and the result, an improvement in the health, is obvious. The diseased organs of digestion have sufficient power to place the diminished amount of food in equilibrium with the inspired oxygen; in the colder climate, the organs of respiration themselves would have been consumed in furnishing the necessary resistance to the action of the atmospheric oxygen.

In our climate, hepatic diseases, or those arising from excess of carbon, prevail in summer; in winter, pulmonic diseases, or those arising from excess of oxygen, are more frequent.

The cooling of the body, by whatever cause it may be produced, increases the amount of food necessary. The mere exposure to the open air, in a carriage or on the deck of a ship, by increasing radiation and vaporization, increases the loss of heat, and compels us to eat more than usual. The same is true of those who are accustomed to drink large quantities of cold water, which is given off at the temperature of the body, 98·5°. It increases the appetite, and persons of weak constitution find it necessary, by continued exercise, to supply to the system the oxygen required to restore the heat abstracted by the cold water. Loud and long continued speaking, the crying of infants, moist air, all exert a decided and appreciable influence on the amount of food which is taken.

IV. In the foregoing pages, it has been assumed that it is especially carbon and hydrogen which, by combining with oxygen, serve to produce animal heat. In fact, observation proves that the hydrogen of the food plays a not less important part than the carbon.

The whole process of respiration appears most clearly developed, when we consider the state of a man, or other animal, totally deprived of food.

The first effect of starvation is the disappearance of fat, and this fat cannot be traced in the urine or in the scanty fæces. Its carbon and hydrogen have been given off through the skin and lungs in the form of oxidised products; it is obvious that they have served to support respiration.

In the case of a starving man, 32½ oz. of oxygen enter the system daily, and are given out again in combination with a part of his body. Currie mentions the case of an individual who was unable to swallow, and whose body lost 100 lbs. in weight during a month; and, according to Martell (Trans. Linn. Soc., vol. xi. p. 411,) a fat pig, overwhelmed in a slip of earth, lived 160 days without food, and was found to have diminished in weight, in that time, more than 120 lbs. The whole history of hybernating animals, and the well established facts of the periodical accumulation, in various animals, of fat, which, at other periods, entirely disappears, prove that the oxygen, in the respiratory process, consumes, without exception, all such substances as are capable of entering into combination with it. It combines with whatever is presented to it, and the deficiency of hydrogen is the only reason why carbonic acid is the chief product; for, at the temperature of the body, the affinity of hydrogen for oxygen far surpasses that of carbon for the same element.

We know, in fact, that the graminivora expire a volume of carbonic acid equal to that of the oxygen inspired, while the carnivora, the only class of animals whose food contains fat, inspire more oxygen than is equal in volume to the carbonic acid expired. Exact experiments have shown, that in many cases only half the volume of oxygen is expired in the form of carbonic acid. These observations cannot be gainsaid, and are far more convincing than those arbitrary and artificially produced phenomena, sometimes called experiments; experiments which, made as too often they are, without regard to the necessary and natural conditions, possess no value, and may be entirely dispensed with; especially when, as in the present case, nature affords the opportunity for observation, and when we make a rational use of that opportunity.

In the progress of starvation, however, it is not only the fat which disappears, but also, by degrees, all such of the solids as are capable of being dissolved. In the wasted bodies of those who have suffered starvation, the muscles are shrunk and unnaturally soft, and have lost their contractility; all those parts of the body which were capable of entering into the state of motion, have served to protect the remainder of the frame from the destructive influence of the atmosphere. Towards the end, the particles of the brain begin to undergo the process of oxidation, and delirium, mania, and death close the scene; that is to say, all resistance to the oxidising power of the atmospheric oxygen ceases, and the chemical process of eremacausis, or decay, commences, in which every part of the body, the bones excepted, enters into combination with oxygen.

The time which is required to cause death by starvation depends on the amount of fat in the body, on the degree of exercise, as in labour or exertion of any kind, on the temperature of the air, and finally, on the presence or absence of water. Through the skin and lungs there escapes a certain quantity of water, and as the presence of water is essential to the continuance of the vital motions, its dissipation hastens death. Cases have occurred, in which a full supply of water being accessible to the sufferer, death has not occurred, till after the lapse of twenty days. In one case, life was sustained in this way for the period of sixty days.

In all chronic diseases death is produced by the same cause, namely, the chemical action of the atmosphere. When those substances are wanting, whose function in the organism is to support the process of respiration; when the diseased organs are incapable of performing their proper function of producing these substances; when they have lost the power of transforming the food into that shape in which it may, by entering into combination with the oxygen of the air, protect the system from its influence, then, the substance of the organs themselves, the fat of the body, the substance of the muscles, the nerves, and the brain, are unavoidably consumed.*

The true cause of death in these cases is the respiratory process, that is, the action of the atmosphere.

A deficiency of food, and the want of power to convert the food into a part of the organism, are both, equally a want of resistance; and this is the negative cause of the cessation of the vital process. The flame is extinguished, because the oil is consumed; and it is the oxygen of the air which has consumed it.

In many diseases substances are produced which are incapable of assimilation. By the mere deprivation of food, these substances are removed from the body without leaving a trace behind; their elements have entered into combination with the oxygen of the air.

From the first moment that the function of the lungs or of the skin is interrupted or disturbed, compounds, rich in carbon, appear in the urine, which acquires a brown colour. Over the whole surface of the body oxygen is absorbed, and combines with all the substances which offer no resistance to it. In those parts of the body where the access of oxygen is impeded; for example, in the armpits, or in the soles of the feet, peculiar compounds are given out, recognisable by their appearance, or by their odour. These compounds contain much carbon.

Respiration is the falling weight, the bent spring, which keeps the clock in motion; the inspirations and expirations are the strokes of the pendulum which regulate it. In our ordinary timepieces, we know with mathematical accuracy the effect produced on their rate of going, by changes in the length of the pendulum, or in the external temperature. Few, however, have a clear conception of the influence of air and temperature on the health of the human body; and yet the research into the conditions necessary to keep it in the nominal state, is not more difficult than in the case of a clock.

V. The want of a just conception of force and effect, and of the connection of natural phenomena, has led chemists to attribute a part of the heat generated in the animal body to the action of the nervous system. If this view exclude chemical action, or changes in the arrangement of the elementary particles, as a condition of nervous agency, it means nothing else than to derive the presence of motion, the manifestation of a force, from nothing. But no force, no power can come of nothing.

No one will seriously deny the share which the nervous apparatus has in the respiratory process; for no change of condition can occur in the body without the nerves; they are essential to all vital motions. Under their influence, the viscera produce those compounds, which, while they protect the organism from the action of the oxygen of the atmosphere, give rise to animal heat; and when the nerves cease to perform their functions, the whole process of the action of oxygen must assume another form. When the pons Varolii is cut through in the dog, or when a stunning blow is inflicted on the back of the head, the animal continues to respire for some time, often more rapidly than in the nominal state; the frequency of the pulse at first rather increases than diminishes, yet the animal cools as rapidly as if sudden death had occurred. Exactly similar observations have been made on the cutting of the spinal chord, and of the par vagum. The respiratory motions continue for a time, but the oxygen does not meet with those substances with which, in the normal state, it would have combined; because the paralysed viscera will no longer furnish them. The singular idea that the nerves produce animal heat, has obviously arisen from the notion that the inspired oxygen combines with carbon, in the blood itself; in which case the temperature of the body, in the above experiments, certainly, ought not to have sunk. But, as we shall afterwards see, there cannot be a more erroneous conception than this.

As by the division of the pneumogastric nerves the motion of the stomach and the secretion of the gastric juice are arrested, and an immediate check is thus given to the process of digestion, so the paralysis of the organs of vital motion in the abdominal viscera affects the process of respiration. These processes are most intimately connected, and every disturbance of the nervous system or of the nerves of digestion re-acts visibly on the process of respiration.

The observation has been made, that heat is produced by the contraction of the muscles, just as in a piece of caoutchouc, which, when rapidly drawn out, forcibly contracts again, with disengagement of heat. Some have gone so far as to ascribe a part of the animal heat to the mechanical motions of the body, as if these motions could exist without an expenditure of force consumed in producing them; how then, we may ask, is this force produced?

By the combustion of carbon, by the solution of a metal in an acid, by the combination of the two electricities, positive and negative, by the absorption of light, and even by the rubbing of two solid bodies together with a certain degree of rapidity, heat may be produced.

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* For an account of what really takes place in this process, I refer to the considerations on the means by which the change of matter is effected in the body of the carnivora, which will be found farther on.

By a number of causes, in appearance entirely distinct, we can thus produce one and the same effect. In combustion and in the production of galvanic electricity, we have a change of condition in material particles; when heat is produced by the absorption of light or by friction, we have the conversion of one kind of motion into another, which affects our senses differently. In all such cases we have a something given, which merely takes another form; in all we have a force and its effect. By means of the fire which heats the boiler of a steam engine we can produce every kind of motion, and by certain amount of motion we can produce fire.

When we rub a piece of sugar briskly on an iron grater, it undergoes, at the surfaces of contact, the same change as if exposed to heat; and two pieces of ice, when rubbed together, melt at the point of contact.

Let us remember that the most distinguished authorities in physics consider the phenomena of heat as phenomena of motion, because the very conception of the *creation* of matter, even though imponderable, is absolutely irreconcilable with its production by mechanical causes, such as friction or motion.

But, admitting all the influence which electric or magnetic disturbances in the animal body can have on the functions of its organs, still the ultimate cause of all these forces is a change of condition in material particles, which may be expressed by the conversion, within a certain time, of the elements of the food into oxidised products. Such of these elements as do not undergo this process of slow combustion, are given off unburned or incombustible in the excrements.

Now, it is absolutely impossible that a given amount of carbon or hydrogen, whatever different forms they may assume in the progress of the combustion, can produce more heat than if directly burned into atmospheric air or in oxygen gas.

When we kindle a fire under a steam engine, and employ the power obtained to produce heat by friction, it is impossible that the heat thus obtained can ever be greater than that which was required to heat the boiler; and if we use the galvanic current to produce heat, the amount of heat obtained is never in any circumstances, greater than we might have by the combustion of the zinc which has been dissolved in the acid.

The contraction of muscles produces heat; but the force necessary for the contraction has manifested itself through the organs of motion, in which it has been excited by chemical changes. The ultimate cause of the heat produced is, therefore, to be found in these chemical changes.

By dissolving a metal in an acid, we produce an electrical current; this current, if passed through a wire, converts the wire into a magnet, by means of which, many different effects may be produced. The cause of this phenomena is magnetism; the cause of the magnetic phenomena is to be found in the electrical current; and the ultimate cause of the electrical current is found to be a chemical change, a chemical action.

There are various causes by which force or motion may be produced. A bent spring, a current of air, the fall of water, fire applied to a boiler, the solution of a metal in an acid,—all these different causes of motion may be made to produce the same effect. But in the animal body we recognise as the ultimate cause of all force only one cause, the chemical action which the elements of the food and the oxygen of the air mutually exercises on each other. The only known ultimate cause of vital force, either in animals or in plants, is a chemical process. If this be prevented, the phenomena of life do not manifest themselves, or they cease to be recognisable by our senses. If the chemical action be impeded, the vital phenomena must take new forms.

According to the experiments of Despretz, 1 oz. of carbon evolves, during its combustion, as much heat as would raise the temperature of 105 oz. of water at 32° to 167°, that is, by 135 degrees; in all, therefore, 105 times $135^{\circ}=14207$ degrees of heat. Consequently, the 13·9 oz. of carbon which are daily converted into carbonic acid in the body of an adult, evolve $13{\cdot}9\times14207^{\circ}=197477{\cdot}3$ degrees of heat. This amount of heat is sufficient to raise the temperature of 1 oz. of water by that number of degrees, or from 32° to 197509·3°; or to cause 136·8 lbs. of water at 32° to boil; or to heat 370 lbs. of water to 98·3° (the temperature of the human body;) or to convert into vapour 24 lbs. of water at 98·3°.

If we now assume that the quantity of water vaporized through the skin and lungs in 24 hours amounts to 48 oz. (3 lbs.,) then there will remain, after deducting the necessary amount of heat, 146380·4 degrees of heat, which are dissipated by radiation, by heating the expired air, and in the excrementitious matters.

In this calculation, no account has been taken of the heat evolved by the hydrogen of the food, during its conversion into water by oxidation within the body. But if we consider that the specific heat of the bones, of fat, and of the organs generally, is far less than that of water, and that consequently they require, in order to be heated to 98·3°, much less heat than an equal weight of water, no doubt can be entertained, that when all the concomitant circumstances are included in the calculation, the heat evolved in the process of combustion, to which the food is subjected in the body, is amply sufficient to explain the constant temperature of the body, as well as the evaporation from the skin and lungs.

VI. All experiments hitherto made on the quantity of oxygen which an animal consumes in a given time, and also the condi sions deduced from them as the origin of animal heat, are destitute of practical value in regard to this question, since we have seen that the quantity of oxygen consumed varies according to the temperature and density of the air, according to the degree of motion, labour, or exercise, to the amount and quality of food, to the comparative warmth of the clothing, and also according to the time within which the food is taken. Prisoners in the Bridewell at Marienschloss (a prison where labour is enforced,) do not consume more than 10·5 oz. of carbon daily; those in the House of Arrest at Giessen, who are deprived of all exercise, consume only 8·5 oz.; (6) and in a family well known to me, consisting of nine individuals, five adults, and four children of different ages, the average daily consumption of carbon for each, is not more than 9·5 oz. of carbon.* We may safely assume, as an approximation, that the quantities of oxygen consumed in these different cases are in the ratio of these numbers; but where the food contains meat, fat, and wine, the proportions are altered by reason of the hydrogen in these kinds of food which is oxidised, and which, in being converted into water, evolves much more heat for equal weights.

The attempts to ascertain the amount of heat evolved in an animal for a given consumption of oxygen have been equally unsatisfactory. Animals have been allowed to respire in close chambers surrounded with cold water; the increase of temperature in the water has been measured by the thermometer, and the quantity of oxygen consumed has been calculated from the analysis of the air before and after the experiment. In experiments thus conducted, it has been found that the animal lost about $\frac{1}{10}$ more heat than corresponded to the oxygen consumed; and had the windpipe of the animal been tied, the strange result would have been obtained of a rise in the temperature of the water without any consumption of oxygen. The animal was at the temperature of 98° or 99°, and the water, in the experiments of Despretz, was at 47·5°. Such experiments consequently prove, that when a great difference exists between the temperature of the animal body and that of the surrounding medium, and when no motion is allowed, more heat is given off than corresponds to the oxygen consumed. In equal times, with free and unimpeded motion, a much larger quantity of oxygen would be consumed without a perceptible increase in the amount of heat lost. The cause of these phenomena is obvious. They appear naturally both in man and animals at certain seasons of the year, and we say in such cases that we are freezing, or experience the sensation of cold. It is plain, that if we were to clothe a man in a metallic dress, and tie up his hands and feet, the loss of heat, for the same consumption of oxygen, would be far greater than if we were to wrap him up in fur and woollen cloth. Nay, in the latter case, we should see him begin to perspire, and warm water would exude, in drops, through the finest pores of his skin.

If to these considerations we add, that decisive experiments are on record, in which animals were made to respire in an unnatural position, as for example, lying on the back, with the limbs tied so as to preclude motion, and that the temperature of their bodies was found to sink in a degree appreciable by the thermometer, we can hardly be at a loss what value we ought to attach to the conclusions drawn from such experiments as those above described.

These experiments and the conclusions deduced from them, in short, are incapable of furnishing the smallest support to the opinion that there exists, in the animal body, any other unknown source of heat, besides the mutual chemical action between the elements of the food and the oxygen of the air. The existence of the latter cannot be doubted or denied, and it is amply sufficient to explain all the phenomena.

VII. If we designate the production of force, the phenomena of motion in the animal body as *nervous life*, and the resistance, the condition of static equilibrium, as *vegetative life;* it is obvious that in all classes of animals the latter, namely, vegetative life, prevails over the former, nervous life, in the earlier stages of existence.

The passage or change of matter from a state of motion to a state of rest appears in an increase of the mass, and in the supply of waste; while the motion itself, or the production of force, appears in the shape of waste of matter.

In a young animal, the waste is less than the increase; and the female retains, up to a certain age, this peculiar condition of a more intense vegetative life. This condition does not cease in the female as in the male, with the complete development of all the organs of the body.

The female in the lower animals, is, at certain seasons, capable of reproduction of the species. The vegetative life in her organism is rendered more intense by certain external conditions, such as temperature, food, &c.; the organism produces more than is wasted, and the result is the capacity of reproduction.

In the human species, the female organism is independent of those external causes which increase the intensity of vegetative life. When the organism is fully developed, it is at all times capable of reproduction of the species; and infinite wisdom has given to the female body the power, up to a certain age, of producing all parts of its organization in greater quantity than is required to supply the daily waste.

This excess of production can be shown to contain all the elements of a new organism, it is constantly accumulating, and is periodically expelled from the body, until it is expended in reproduction. This periodical discharge ceases when the ovum has been impregnated, and from this time every drop of the superabundant blood goes to produce an organism like that of the mother.

Exercise and labour cause a diminution in the quantity of the menstrual discharge; and when it is suppressed in consequence of disease, the vegetative life is manifested in a morbid production of fat. When the equilibrium between the vegetative and nervous life is disturbed in the male, when, as in eunuchs, the intensity of the latter is diminished, the predominance of the former is shown in the same form, in an increased deposit of fat.

VIII. If we hold, that increase of mass in the animal body, the development of its organs, and the supply of waste,—that all this is dependent on the blood, that is, on the ingredients of the blood, then only those substances can properly be called nutritious, or considered as food which are capable of conversion into blood. To determine, therefore, what substances are capable of affording nourishment, it is only necessary to ascertain the composition of the food, and to compare it with that of the ingredients of the blood.

Two substances require especial consideration as the chief ingredients of the blood; one of these separates immediately from the blood when withdrawn from the circulation. It is well known that in this case blood coagulates, and separates into a yellowish liquid, the *serum* of the blood, and a gelatinous mass, which adheres to a rod or stick in soft, elastic fibres, when coagulating blood is briskly stirred. This is the *fibrine* of the blood, which is identical in all its properties with muscular fibre, when the latter is purified from all foreign matters.

The second principal ingredient of the blood is contained in the serum, and gives to this liquid all the properties of the white of eggs, with which it is identical. When heated, it coagulates into a white elastic mass, and the coagulating substance is called *albumen.*

Fibrine and albumen, the chief ingredients of blood, contain, in all, seven chemical elements, among which nitrogen, phosphrus, and sulphur are found. They contain also the earth of bones. The serum retains in solution sea salt and other salts of potash and soda, in which the acids are carbonic, phosphoric, and sulphuric acids. The globules of the blood contain fibrine and albumen, along with a red colouring matter, in which iron is a constant element. Beside these, the blood contains certain fatty bodies in small quantity, which differ from ordinary fats in several of their properties.

Chemical analysis has led to the remarkable result, that fibrine and albumen contain the same organic elements united in the same proportion, so that two analyses, the one of fibrine and the other of albumen, do not differ more than two analyses of fibrine or two of albumen respectively do, in the composition of 100 parts.

In these two ingredients of blood the particles are arranged in a different order, as is shown by the difference of their external properties; but in chemical composition, in the ultimate proportion of the organic elements, they are identical.

This conclusion has lately been beautifully confirmed by a distinguished physiologist (Dénis,) who has succeeded in converting fibrine into albumen, that is, in giving it the solubility, and coagulability by heat, which characterize the white of egg.

Fibrine and albumen, besides having the same composition, agree also in this, that both dissolve in concentrated muriatic acid, yielding a solution of an intense purple colour. This solution, whether made with fibrine or albumen, has the very same reactions with all substances yet tried.

Both albumen and fibrine, in the process of nutrition, are capable of being converted into muscular fibre, and muscular fibre is capable of being reconverted into blood. These facts have long been established by physiologists, and chemistry has merely proved that these metamorphoses can be accomplished under the influence of a certain force, without the aid of a third substance, or of its elements, and without the addition of any foreign element, or the separation of any element previously present in these substances.

If we now compare the composition of all organized parts with that of fibrine and albumen, the following relations present themselves:

All parts of the animal body which have a decided shape, which forms parts of organs, contain nitrogen. No part of an organ which possesses motion and life is destitute of nitrogen; all of them contain likewise carbon and the elements of water, the latter, however, in no case in the proportion to form water.

The chief ingredients of the blood contain nearly 17 per cent. of nitrogen, and no part of an organ contains less than 17 per cent. of nitrogen. (7)

The most convincing experiments and observations have proved that the animal body is absolutely incapable of producing an elementary body, such as carbon or nitrogen, out of substances which do not contain it; and it obviously follows, that all kinds of food fit for the production either of blood, or of cellular tissue, membranes, skin, hair, muscular fibre, &c., must contain a certain amount of nitrogen, because that element is essential to the composition of the above named organs; because the organs cannot create it from the other elements presented to them; and, finally, because no nitrogen is absorbed from the atmosphere in the vital process.

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* In this family, the monthly consumption was 151 lbs. of brown bread, 70 lbs. white bread, 132 lbs. meat, 19 lbs. sugar, 15·9 lbs. butter, 57 maass (about 24 gallons) of milk; the carbon of the potatoes and other vegetables, of the poultry, game, and wine consumed, having been reckoned as equal to that contained in the excrementitious matters, the carbon of the above articles was considered as being converted into carbonic acid.

The substance of the brain and nerves contains a large quantity of albumen, and, in addition to this, two peculiar fatty acids, distinguished from other fats by containing phosphorus (phosphoric acid?) One of these contains nitrogen (Frémy.)

Finally, water and common fat are those ingredients of the body which are destitute of nitrogen. Both are amorphus or unorganized, and only so far take part in the vital process as that their presence is required for the due performance of the vital functions. The inorganic constituents of the body are, iron, lime, magnesia, common salt, and the alkalies.

IX. The nutritive process in the carnivora is seen in its simplest form. This class of animals lives on the blood and flesh of the graminivora; but this blood and flesh is, in all its properties, identical with their own. Neither chemical nor physiological differences can be discovered.

The nutriment of carnivorous animals is derived originally from blood; in their stomach it becomes dissolved, and capable of reaching all other parts of the body; in its passage it is again converted into blood, and from this blood are reproduced all those parts of their organization which have undergone change or metamorphosis.

With the exception of hoofs, hair, feathers, and the earth of bones, every part of the food of carnivorous animals is capable of assimilation.

In a chemical sense, therefore, it may be said that a carnivorous animal, in supporting the vital process, consumes itself. That which serves for its nutrition is identical with those parts of its organization which are to be renewed.

The process of nutrition in graminivorous animals appear at first sight altogether different. Their digestive organs are less simple, and their food consists of vegetables, the great mass of which contains but little nitrogen.

From what substances, it may be asked, is the blood formed, by means of which their organs are developed? This question may be answered with certainty.

Chemical researches have shown, that all such parts of vegetables as can afford nutriment to animals contain certain constituents which are rich in nitrogen; and the most ordinary experience proves that animals require for their support and nutrition less of these parts of plants in proportion as they abound in the nitrogenized constituents. Animals cannot be fed on matters destitute of these nitrogenized constituents.

These important products of vegetation are especially abundant in the seeds of the different kinds of grain, and of pease, beans, and lentils: in the roots and the juices of what are commonly called vegetables. They exist, however, in all plants, without exception, and in every part of plants in larger or smaller quantity.

These nitrogenized forms of nutriment in the vegetable kingdom may be reduced to three substances, which are easily distinguished by their external characters. Two of them are soluble in water, the third is insoluble.

When the newly expressed juices of vegetables are allowed to stand, a separation takes place in a few minutes. A gelatinous precipitate, commonly of a green tinge, is deposited, and this, when acted on by liquids which remove the colouring matter, leaves a grayish white subtance, well known to druggists as the deposit from vegetable juices. This is one of the nitrogenized compounds which serves for the nutrition of animals, and has been named *vegetable fibrine*. The juice of grapes is especially rich in this constituent, but it is most abundant in the seeds of wheat, and of the cerealia. It may be obtained from wheat flour by a mechanical operation, and in a state of tolerable purity; it is then called *gluten*, but the glutinous property belongs, not to vegetable fibrine, but to a foreign substance, present in small quantity, which is not found in the other cerealia.

The method by which it is obtained sufficiently proves that it is insoluble in water; although we cannot doubt that it was originally dissolved in the vegetable juice, from which it afterwards separated, exactly as fibrine does from blood.

The second nitrogenized compound remains dissolved in the juice after the separation of the fibrine. It does not separate from the juice at the ordinary temperature, but is instantly coagulated when the liquid containing it is heated to the boiling point.

When the clarified juice of nutritious vegetables, such as cauliflower, asparagus, mangel wurzel, or turnips, is made to boil, a coagulum is formed, which it is absolutely impossible to distinguish from the substance which separates as coagulum, when the serum of blood or the white of an egg, diluted with water, are heated to the boiling point. This is *vegetable albumen*. It is found in the greatest abundance in certain seeds, in nuts, almonds, and others, in which the starch of the gramineæ is replaced by oil.

The third nitrogenized constituent of the vegetable food of animals is *vegetable caseine*. It is chiefly found in the seeds of pease, beans, lentils, and similar leguminous seeds. Like vegetable albumen, it is soluble in water, but differs from it in this, that its solution is not coagulated by heat. When the solution is heated or evaporated, a skin forms on its surface, and the addition of an acid causes a coagulum, just as in animal milk.

These three nitrogenized compounds, vegetable fibrine, albumen, and caseine, are

the true nitrogenized constituents of the food of graminivorous animals; all other nitrogenized compounds, occurring in plants, are either rejected by animals, as in the case of the characteristic principles of poisonous and medicinal plants, or else they occur in the food in such very small proportion, that they cannot possibly contribute to the increase of mass in the animal body.

The chemical analysis of these three substances has led to the very interesting result that they contain the same organic elements, united in the same proportion by weight; and, what is still more remarkable, that they are identical in composition with the chief constituents of blood, animal fibrine, and albumen. They all three dissolve in concentrated muriatic acid with the same deep purple colour, and even in their physical characters, animal fibrine and albumen are in no respect different from vegetable fibrine and albumen. It is especially to be noticed, that by the phrase, identity of composition we do not here imply mere similarity, but that even in regard to the presence and relative amount of sulphur, phosphorus, and phosphate of lime, no difference can be observed. (8)

How beautifully and admirably simple, with the aid of these discoveries, appears the process of nutrition in animals, the formation of their organs, in which vitality chiefly resides! Those vegetable principles, which in animals are used to form blood, contain the chief constituents of blood, fibrine and albumen, ready formed, as far as regards their composition. All plants, besides, contain a certain quantity of iron, which reappears in the colouring matter of the blood. Vegetable fibrine and animal fibrine, vegetable albumen and animal albumen, hardly differ even in form; if these principles be wanting in the food, the nutrition of the animal is arrested; and when they are present, the graminivorous animal obtains in its food the very same principles on the presence of which the nutrition of the carnivora entirely depends.

Vegetables produce in their organism the blood of all animals, for the carnivora, in consuming the blood and flesh of the graminivora, consume, strictly speaking, only the vegetable principles which have served for the nutrition of the latter. Vegetable fibrine and albumen take the same form in the stomach of the graminivorous animal as animal fibrine and albumen do in that of the carnivorous animal.

From what has been said, it follows that the development of the animal organism and its growth are dependent on the reception of certain principles identical with the chief constituents of blood.

In this sense we may say that the animal organism gives to blood only its form; that it is incapable of creating blood out of other substances which do not already contain the chief constituents of that fluid. We cannot, indeed, maintain that the animal organism has no power to form other compounds, for we know that it is capable of producing an extensive series of compounds, differing in composition from the chief constituents of blood; but these last, which form the starting point of the series, it cannot produce.

The animal organism is a higher kind of vegetable, the development of which begins with those substances, with the production of which the life of an ordinary vegetable ends. As soon as the latter has borne seed, it dies, or a period of its life comes to a termination.

In that endless series of compounds, which begins with carbonic acid, ammonia, and water, the sources of the nutrition of vegetables, and includes the most complex constituents of the animal brain, there is no blank, no interruption. The first substance capable of affording nutriment to animals is the last product of the creative energy of vegetables.

The substance of cellular tissue and of membranes, of the brain and nerves, these the vegetable cannot produce.

The seemingly miraculous in the productive agency of vegetables disappears in a great degree, when we reflect that the production of the constituents of blood cannot appear more surprising than the occurrence of the fat of beef and mutton in cocoa beans, of human fat in olive oil, of the principal ingredient of butter in palm oil, and of horse fat and train oil in certain only seeds.

X. While the preceding considerations leave little or no doubt as to the way in which the increase of mass in an animal, that is, its growth, is carried on, there is yet to be resolved a most important question, namely, that of the function performed in the animal system by substances containing no nitrogen, such as sugar, starch, gum, pectine, &c.

The most extensive class of animals, the graminivora, cannot live without these substances; their food must contain a certain amount of one or more of them, and if these compounds are not supplied, death quickly ensues.

This important inquiry extends also to the constituents of the food of carnivorous animals in the earliest periods of life; for this food also contains substances which are not necessary for their support in the adult state.

The nutrition of the young of carnivora is obviously accomplished by means similar to those by which the graminivora are nourished; their development is dependant on the supply of a fluid, which the body of the mother secretes in the shape of milk.

Milk contains only one nitrogenized constituent, known under the name of *caseine*; besides this, its chief ingredients are butter, (fat), and sugar of milk.

The blood of the young animal, its muscular fibre, cellular tissue, nervous matter, and bones, must have derived their origin from the nitrogenized constituent of milk, the caseine; for butter and sugar of milk contain no nitrogen.

Now, the analysis of caseine has led to the result, which, after the details given in the last section, can hardly excite surprise, that this substance also is identical in composition with the chief constituents of blood, fibrine and albumen. Nay, more, a comparison of its properties with those of vegetable caseine has shown that these two substances are identical in all their properties; insomuch that certain plants, such as peas, beans, and lentils, are capable of producing the same substance which is formed from the blood of the mother, and employed in yielding the blood of the young animal. (9)

The young animal, therefore, receives, in the form of caseine, which is distinguished from fibrine and albumen by its great solubility, and by not coagulating when heated, the chief constituent of the mother's blood. To convert caseine into blood no foreign substance is required, and in the conversion of the mother's blood into caseine, no elements of the constituents of the blood have been separated. When chemically examined, caseine is found to contain a much larger proportion of the earth of bones than blood does, and that in a very soluble form, capable of reaching every part of the body. Thus, even in the earliest period of its life, the development of the organs, in which vitality resides, is, in the carnivorous animal, dependant on the supply of a substance, identical in organic composition with the chief constituents of its blood.

What, then, is the use of the butter and the sugar of milk? How does it happen that these substances are indispensable to life?

Butter and sugar of milk contain no fixed bases, no soda or potash. Sugar of milk has a composition closely allied to that of the other kinds of sugar, of starch, and of gum; all of them contain carbon and the elements of water, the latter precisely in the proportion to form water.

There is added, therefore, by means of these compounds, to the nitrogenized constituents of food, a certain amount of carbon, or, as in the case of butter, of carbon and hydrogen; that is, an excess of elements, which cannot possibly be employed in the production of blood, because the nitrogenized substances contained in the food already contain exactly the amount of carbon which is required for the production of fibrine and albumen.

The following considerations will show that hardly a doubt can be entertained, that this excess of carbon alone, or of carbon and hydrogen, is expended in the production of animal heat, and serves to protect the organism from the action of the atmospheric oxygen.

XI. In order to obtain a clearer insight into the nature of the nutritive process in both the great classes of animals, let us first consider the changes which the food of the carnivora undergoes in their organism.

If we give to an adult serpent, or boa constrictor, a goat, a rabbit, or a bird, we find that the hair, hoofs, horns, feathers, or bones of these animals, are expelled from the body apparently unchanged. They have retained their natural form and aspect, but have become brittle, because of all their component parts they have lost only that one which was capable of solution, namely, the gelatine. Fæces, properly so called, do not occur in serpents any more than in carnivorous birds.

We find, moreover, that when the serpent has regained its original weight, every other part of its prey, the flesh, the blood, the brain, and nerves, in short, every thing has disappeared.

The only excrement, strictly speaking is a substance expelled by the urinary passage. When dry, it is pure white, like chalk; it contains much nitrogen, and a small quantity of carbonate and phosphate of lime mixed with the mass.

This excrement is urate of ammonia, a chemical compound, in which the nitrogen bears to the carbon the same proportion as in bicarbonate of ammonia. For every equivalent of nitrogen it contains two equivalents of carbon.

But muscular fibre, blood membranes, and skin, contain four times as much carbon for the same amount of nitrogen, or eight equivalents to one; and if we add to this the carbon of the fat and nervous substance, it is obvious that the serpent has consumed for every equivalent of nitrogen, much more than eight equivalents of carbon.

If now we assume that the urate of ammonia contains all the nitrogen of the animal consumed, then at least six equivalents of carbon, which were in combination with this nitrogen, must have been given out in a different form from the two equivalents which are found in the urate of ammonia.

Now we know, with perfect certainty, that this carbon has been given out through the skin and lungs, which could only take place in the form of an oxidized product.

The excrements of a buzzard which had been fed with beef, when taken out of the rectum, consisted, according to L. Gmelin and Tiedemann, of urate of ammonia. In like manner, the fæces in lions and tigers are scanty and dry, consisting chiefly of bone earth, with mere traces of compounds containing carbon; but their urine contains, not urate of ammonia, but urea, a compound in which carbon and nitrogen are to each other in the same ratio as in *neutral* carbonate of ammonia.

Assuming that their food (flesh, &c.) contains carbon and nitrogen in the ratio of eight equivalents to one, we find these elements in their urine in the ratio of one equivalent to one; a smaller proportion of carbon, therefore, than in serpents, in which respiration is so much less active.

The whole of the carbon and hydrogen which the food of these animals contained, beyond the amount which we find in their excrements, has disappeared, in the process of respiration, as carbonic acid and water.

Had the animal food been burned in a furnace, the change produced in it would only have differed in the form of combination assumed by the nitrogen from that which it underwent in the body of the animal. The nitrogen would have appeared, with part of the carbon and hydrogen, as carbonate of ammonia, while the rest of the carbon and hydrogen would have formed carbonic acid and water. The incombustible parts would have taken the form of ashes, and any part of the carbon unconsumed from a deficiency of oxygen would have appeared as soot, or lamp-black. Now the solid excrements are nothing else than the incombustible, or imperfectly burned, parts of the food.

In the preceding pages it has been assumed that the elements of the food are converted by the oxygen absorbed in the lungs into oxidized products; the carbon into carbonic acid, the hydrogen into water, and the nitrogen into a compound containing the same elements as carbonate of ammonia.

This is only true in appearance; the body, no doubt, after a certain time, acquires its original weight. The amount of carbon, and of the other elements, is not found to be increased—exactly as much carbon, hydrogen, and nitrogen has been given out as was supplied in the food; but nothing is more certain than that the carbon, hydrogen, and nitrogen given out, although equal in amount to what is supplied in that form, do not directly proceed from the food.

It would be utterly irrationable to suppose that the necessity of taking food, or the satisfying the appetite, had no other object than the production of urea, uric acid, carbonic acid, and other excrementitious matters—of substances which the system expels, and consequently applies to no useful purpose in the economy.

In the adult animal, the food serves to restore the waste of matter; certain parts of its organs have lost the state of vitality, have been expelled from the substance of the organs, and have been metamorphosed into new combinations, which are amorphous and unorganized.

The food of the carnivora is at once converted into blood; out of the newly formed blood those parts of organs which have undergone metamorphoses are reproduced. The carbon and nitrogen of the food thus become constituent parts of organs.

Exactly as much carbon and nitrogen is supplied to the organs by the blood, that is, ultimately, by the food, as they have lost by the transformations attending the exercise of their functions.

What then, it may be asked, becomes of the new compounds produced by the transformations of the organs, of the muscles, of the membranes and cellular tissue of the nerves and brain?

These new compounds cannot, owing to their solubility, remain in the situation where they are formed, for a well known force, namely the circulation of the blood, opposes itself to this.

By the expansion of the heart, an organ in which two systems of tubes meet, which are ramified in a most minute network of vessels through all parts of the body, there is produced a vacuum, the immediate effect of which is, that all fluids which can penetrate into these vessels are urged with great force towards one side of the heart by the external pressure of the atmosphere. This motion is powerfully assisted by the contraction of the heart, alternating with its expansion, and caused by a force independent of the atmospheric pressure.

In a word, the heart is a forcing pump, which sends arterial blood into all parts of the body; and also a suction pump, by means of which all fluids of whatever kind, as soon as they enter the absorbent vessels which communicate with the veins, are drawn towards the heart. This suction, arising from the vacuum caused by the expansion of the heart, is a purely mechanical act, which extends, as above stated, to fluids of every kind, to saline solutions, poisons, &c. It is obvious, therefore, that by the forcible entrance of arterial blood into the capillary vessels, the fluids contained in these, in other words, the soluble compounds formed by the transformations of organized parts, must be compelled to move towards the heart.

These compounds cannot be employed for the reproduction of those tissues from which they are derived. They pass through the absorbent and lymphatic vessels into the veins, where their accumulation would speedily put a stop to the nutritive process, were it not that this accumulation is prevented by two contrivances adapted expressly to this purpose, and which may be compared to filtering machines.

The venous blood, before reaching the heart, is made to pass through the liver; the arterial blood, on the other hand, passes through the kidneys; and these organs separate from both all substances incapable of contributing to nutrition.

Those new compounds which contain the nitrogen of the transformed organs are collected in the urinary bladder, and being utterly incapable of any further application in the system, are expelled from the body.

Those, again, which contain the carbon of the transformed tissues, are collected in the gall bladder in the form of a compound of soda, *the bile*, which is miscible with water in every proportion, and which, passing into the duodenum, mixes with the chyme. All those parts of the bile which, during the digestive process, do not lose their solubility, return during that process into the circulation in a state of extreme division. The soda of the bile, and those highly carbonized portions which are not precipitated by a weak acid (together making

$\frac{88}{100}$ths of the solid contents of the bile,) retain the capacity of resorption by the absorbents of the small and large intestines; nay, this capacity has been directly proved by the administration of enemata containing bile, the whole of the bile disappearing with the injected fluid in the rectum.

Thus we know with certainty, that the nitrogenized compounds, produced by the metamorphosis of organized tissues, after being separated from the arterial blood by means of the kidneys, are expelled from the body as utterly incapable of further alteration; while the compounds, rich in carbon, derived from the same source, return into the system of carnivorous animals.

The food of the carnivora is identical with the chief constituents of their bodies, and hence the metamorphoses which their organs undergo must be the same as those which, under the influence of the vital force, take place in the matters which constitute their food.

The flesh and blood consumed as food yield their carbon for the support of the respiratory process, while its nitrogen appears as uric acid, ammonia, or urea. But previously to these final changes, the dead flesh and blood become living flesh and blood, and it is, strictly speaking, the carbon of the compounds formed in the metamorphoses of living tissues that serves for the production of animal heat.

The food of the carnivora is converted into blood, which is destined for the reproduction of organized tissues; and by means of the circulation a current of oxygen is conveyed to every part of the body. The globules of the blood, which in themselves can be shown to take no share in the nutritive process, serve to transport the oxygen, which they give up in their passage through the capillary vessels. Here the current of oxygen meets with the compounds produced by the transformation of the tissues, and combines with their carbon to form carbonic acid, with their hydrogen to form water. Every portion of these substances which escapes this process of oxidation is sent back into the circulation in the form of the bile, which by degrees completely disappears.

In the carnivora the bile contains the carbon of the metamorphosed tissues; this carbon disappears in the animal body, and the bile likewise disappears in the vital process. Its carbon and hydrogen are given out through the skin and lungs as carbonic acid and water; and hence it is obvious that the elements of the bile serve for respiration and for the production of animal heat. Every part of the food of carnivorous animals is capable of forming blood; their excrements, excluding the urine, contain only inorganic substances, such as phosphate of lime; and the small quantity of organic matter which is found mixed with these is derived from excretions, the use of which is to promote their passage through the intestines, such as mucus. These excrements contain no bile and no soda; for water extracts from them no trace of any substance resembling bile, and yet bile is very soluble in water, and mixes with it in every proportion.

Physiologists can entertain no doubt as to the origin of the constituent parts of the urine and of the bile. When, from the deprivation of food, the stomach contracts itself so as to resemble a portion of intestine, the gall-bladder, for want of the motion which the full stomach gives to it, cannot pour out the bile it contains; hence in animals starved to death we find the gall-bladder distended and full. The secretion of bile and urine goes on during the winter sleep of hybernating animals; and we know that the urine of dogs, fed for three weeks exclusively on pure sugar, contains as much of the most highly nitrogenized constituent, urea, as in the normal condition (Marchaud. Erdmaun's Journal für praktische Chemie, XIV. p. 495.)

Differences in the quantity of urea secreted in these and similar experiments are explained by the condition of the animal in regard to the amount of the natural motions permitted. Every motion increases the amount of organized tissue which undergoes metamorphosis. Thus after a walk, the secretion of urine in man is invariably increased.

The urine of the mammalia, of birds, and of amphibia, contains uric acid or urea; and the excrements of the mollusca, and of insects, as of cantharides and of the butterfly of the silkworm, contain urate of ammonia. This constant occurrence of one or two nitrogenized compounds in the excretions of animals, while so great a difference exists in their food, clearly proves that these compounds proceed from one and the same source.

As little doubt can be entertained in regard to the function of the bile in the vital process. When we consider, that the acetate of potash, given in enema, or simply as a bath for the feet, renders the urine strongly alkaline (Rehberger in Tiedemann's Zeitschrift für Physiologie, ii. 149,) and that the change which the acetic acid here undergoes cannot be conceived without the addition of oxygen, it is obvious, that the soluble constituents of the bile, prone to change in a high degree as we know them to be, and which, as already stated, cannot be employed in the production of blood, must, when returned through the intestines into the circulation, in like manner yield to the influence of the oxygen which they meet. The bile is a compound of soda, the elements of which, with the exception of the soda, disappears in the body of a carnivorous animal.

In the opinion of many of the most distinguished physiologists, the bile is intended solely to be excreted; and nothing is more certain, than that a substance containing so very small a proportion of nitrogen can

have no share in the process of nutrition or reproduction of organized tissue. But quantitative physiology must at once and decidedly reject the opinion, that the bile serves no purpose in the economy, and is incapable of further change.

No part of any organized structure contains soda; only in the serum of the blood, in the fat of the brain, and in the bile, do we meet with that alkali. When the compounds of soda in the blood are converted into muscular fibre, membrane, or cellular tissue, the soda they contain must enter into new combinations. The blood which is transformed into organized tissue gives up its soda to the compounds formed by the metamorphoses of the previously existing tissues. In the bile we find one of those compounds of soda.

Were the bile intended merely for excretion, we should find it, more or less altered, and also the soda it contains, in the solid excrements. But, with the exception of common salt, and of sulphate of soda, which occur in all the animal fluids, only mere traces of soda are to be found in the fæces. The soda of the bile, therefore, at all events, must have returned from the intestinal canal into the organism, and the same must be true of the organic matters which were in combination with it.

According to the observations of physiologists, a man secretes daily from 17 to 24 oz. of bile; a large dog, 36 oz.; a horse 37 lbs. (Burdach's Physiologie, v. p. 260.) But the fæces of a man do not on an average weigh more than 5½ oz.; and those of a horse 28½ lbs., of which 21 lbs. are water, and 7½ lbs. dry fæces. (Boussingault.) The latter yield to alcohol only $\frac{1}{20}$th part of their weight of soluble matter.

If we assume the bile to contain 90 per cent. of water, a horse secretes daily 592 oz. of bile, containing 59·2 oz. of solid matter; while 7½ lbs. or 120 oz. of dried excrement yield only 6 oz. of matter soluble in alcohol, which might possibly be bile. But this matter is not bile; when the alcohol is dissipated by evaporation, there remains a soft, unctuous mass, altogether insoluble in water, and which, when incinerated, leaves no alkaline ashes, no soda. (10.)

During the digestive process, therefore, the soda of the bile, and, along with it, all the soluble parts of that fluid, are returned into the circulation. This soda re-appears in the newly-formed blood, and, finally, we find it in the urine in the form of phosphate, carbonate, and hippurate of soda. Berzelius found in 1,000 parts of fresh human fæces only nine parts of substance similar to bile; 5 ounces, therefore, would contain only 21 grains of dried bile, equivalent to 219 grains of fresh bile. But a man secretes daily from 9,640 to 11,520 grains of fluid bile, that is, from 45 to 56 times as much as can be detected in the matters discharged by the intestinal canal.

Whatever opinion we may entertain of the accuracy of the physiological experiments, in regard to the quantity of bile secreted by the different classes of animals; thus much is certain, that even the maximum of supposed secretion, in man and in the horse, does not contain as much carbon as is given out in respiration. With all the fat which is mixed with it, or enters into its composition, dried bile does not contain more than 69 per cent. of carbon. Consequently, if a horse secretes 57 lbs. of bile, this quantity will contain only 40 ounces of carbon. But the horse expires daily nearly twice as much in the form of carbonic acid. A precisely similar proportion holds good in man.

Along with the matter destined for the formation or reproduction of organs, the circulation conveys oxygen to all parts of the body. Now, into whatever combination the oxygen may enter in the blood, it must be held as certain, that such of the constituents of blood as are employed for reproduction, are not materially altered by it. In muscular fibre we find fibrine, with all the properties it had in venous blood; the albumen in the blood does not combine with oxygen. The oxygen may possibly serve to convert into the gaseous state some unknown constituent of the blood; but those well-known constituents, which are employed in reproduction, cannot be destined to support the respiratory process; none of their properties can justify such an opinion.

Without attempting in this place to exhaust the whole question of the share taken by the bile in the vital operations, it follows, as has been observed, from the simple comparison of those parts of the food of the carnivora which are capable of assimilation, with the ultimate products into which it is converted, that all the carbon of the food, except that portion which is found in the urine, is given out as carbonic acid.

But this carbon was ultimately derived from the substance of the metamorphosed tissues; and this being admitted, the question of the necessity of substances containing much carbon and no nitrogen in the food of the young of the carnivora, and in that of the graminivora, is resolved in a strikingly simple manner.

XII. It cannot be disputed that in an adult carnivorous animal, which neither gains nor loses weight perceptibly from day to day, its nourishment, the waste of organized tissue, and its consumption of oxygen, stand to each other in a well-defined and fixed relation.

The carbon of the carbonic acid given off, with that of the urine; the nitrogen of the urine, and the hydrogen given off as ammonia and water; these elements, taken together, must be exactly equal in weight to the carbon, nitrogen, and hydrogen of the metamorphosed tissues, and since these last are exactly replaced by the food, to the carbon, nitrogen, and hydrogen of the food. Were this not the case, the weight of the animal could not possibly remain unchanged.

But, in the young of the carnivora, the weight does not remain unchanged; on the contrary, it increases from day to day by an appreciable quantity.

This fact presupposes, that the assimilative process in the young animal is more energetic, more intense, than the process of transformation in the existing tissues. If both processes were equally active, the weight of the body could not increase; and were the waste by transformation greater, the weight of the body would decrease.

Now, the circulation in the young animal is not weaker, but, on the contrary, more rapid; the respirations are more frequent; and, for equal bulks, the consumption of oxygen must be greater rather than smaller in the young than in the adult animal. But, since the metamorphosis of organized parts goes on more slowly, there would ensue a deficiency of those substances, the carbon and hydrogen of which are adapted for combination with oxygen; because, in the carnivora it is the new compounds, produced by the metamorphosis of organized parts, which nature has destined to furnish the necessary resistance to the action of the oxygen, and to produce animal heat. What is wanting for these purposes an infinite wisdom has supplied to the young animal in its natural food.

The carbon and hydrogen of butter, and the carbon of the sugar of milk, no part of either of which can yield blood, fibrine, or albumen, are destined for the support of the respiratory process, at an age when a greater resistance is opposed to the metamorphosis of existing organisms; or, in other words, to the production of compounds, which in the adult state are produced in quantity amply sufficient for the purpose of respiration.

The young animal receives the constituents of its blood in the caseine of the milk. A metamorphosis of existing organs goes on, for bile and urine are secreted; the matter of the metamorphosed parts is given off in the form of urine, of carbonic acid, and of water; but the butter and sugar of milk also disappear; they cannot be detected in the fæces.

The butter and sugar of milk are given out in the form of carbonic acid and water, and their conversion into oxidized products furnishes the clearest proof that far more oxygen is absorbed than is required to convert the carbon and hydrogen of the metamorphosed tissues into carbonic acid and water.

The change and metamorphosis of organized tissues going on in the vital process in the young animal, consequently yield, in a given time, much less carbon and hydrogen in the form adapted for the respiratory process than corresponds to the oxygen taken up in the lungs. The substance of its organized parts would undergo a more rapid consumption, and would necessarily yield to the action of the oxygen, were not the deficiency of carbon and hydrogen supplied from another source.

The continued increase of mass, or growth, and the free and unimpeded developement of the organs of the young animal, are dependent on the presence of foreign substances, which, in the nutritive process, have no other function than to protect the newly-formed organs from the action of the oxygen. It is the elements of these substances which unite with the oxygen; the organs themselves could not do so without being consumed; that is, growth, or increase of mass in the body, the consumption of oxygen remaining the same, would be utterly impossible.

The preceding considerations leave no doubt as to the purpose for which Nature has added to the food of the young of carnivorous mammalia substances devoid of nitrogen, which their organism cannot employ for nutrition, strictly so called, that is, for the production of blood; substances which may be entirely dispensed with in their nourishment in the adult state. In the young of carnivorous birds, the want of all motion is an obvious cause of diminished waste in the organized parts; hence, milk is not provided for them.

The nutritive process in the carnivora thus presents itself in two distinct forms; one of which we again meet with in the graminivora.

XIII. In the class of graminivorous animals, we observe, that during their whole life, their existence depends on the supply of substances having a composition identical with that of sugar of milk, or closely resembling it. Every thing that they consume as food contains a certain quantity of starch, or gum, or sugar, mixed with other matters.

The most abundant and widely-extended of the substances of this class is amylon or starch; it occurs in roots, seeds, and stalks, and even in wood, deposited in the form of roundish or oval globules, which differ from each other in size alone, being identical in chemical composition. (11.) In the same plant, in the pea, for example, we find starch, the globules of which differ in size. Those in the expressed juice of the stalks have a diameter of from $\frac{1}{200}$ to $\frac{1}{150}$ of an inch, while those in the seeds are three or four times larger. The globules in arrowroot and in potato starch are distinguished by their large size; those of rice and of wheat are remarkably small.

It is well known that starch may be converted into sugar by very different means. This change occurs in the process of germination, as in malting, and it is easily accomplished by the action of acids. The metamorphosis of starch into sugar depends simply, as is proved by analysis, on the addition of the elements of water. (12.) All the carbon of the starch is found in the sugar; none of its elements have been

separated, and, except the elements of water, no foreign element has been added to it in this transformation.

In many, especially in pulpy fruits, which when unripe are sour and rough to the taste, but when ripe are sweet, as, for example, in apples and pears, the sugar is produced from the starch which the unripe fruit contains.

If we rub unripe apples or pears on a grater to a pulp, and wash this with cold water on a fine sieve, the turpid liquid which passes through deposits a very fine flour of starch, of which not even a trace can be detected in the ripe fruit. Many varieties become sweet while yet on the tree; these are the summer or early apples and pears. Others, again, become sweet only after having been kept for a certain period after gathering. The after-ripening, as this change is called, is a purely chemical process, entirely independent of the vitality of the plant. When vegetation ceases, the fruit is capable of reproducing the species, that is, the kernel, stone, or true seed is fully ripe, but the fleshy covering from this period is subjected to the action of the atmosphere. Like all substances in a state of eremacausis, or decay, it absorbs oxygen, and gives off a certain quantity of carbonic acid gas.

In the same way as the starch in putrefying paste, in which it is in contact with decaying gluten, is converted into sugar, the starch in the above-named fruits, in a state of decay, or eremacausis, is transformed into grape sugar. The more starch the unripe fruit contains, the sweeter does it become when ripe.

A close connexion thus exists between sugar and starch. By means of a variety of chemical actions, which exert no other influence on the elements of starch than that of changing the direction of their mutual attraction, we can convert starch into sugar, but it is always grape sugar.

Sugar of milk in many respects resembles starch; (13) it is, by itself, incapable of the vinous fermentation, but it acquires the property of resolving itself into alcohol and carbonic acid when it is exposed to heat in contact with a substance in the state of fermentation (such as putrefying cheese in milk.) In this case, it is first converted into grape sugar; and it undergoes the same transformation, when it is kept in contact with acids—with sulphuric acid, for example—at the ordinary temperature.

Gum has the same composition in 100 parts as cane sugar. (14.) It is distinguished from the different varieties of sugar by its not possessing the property of being resolved into alcohol and carbonic acid by the process of putrefaction. When placed in contact with fermenting substances, it undergoes no appreciable change, whence we may conclude, with some degree of probability, that its elements, in the peculiar arrangement according to which they are united, are held together with a stronger force than the elements of the different kinds of sugar.

There is, however, a certain relation between gum and sugar of milk, since both of them, when treated with nitric acid, yield the same oxidized product, namely mucic acid, which cannot, under the same circumstances, be formed from any of the other kinds of sugar.

In order to show more distinctly the similarity of composition in these different substances, which perform so important a part in the nutritive process of the graminivora, let us represent one equivalent of carbon by C (=75·8,) and one equivalent of water by *aqua* (=112·4,) we shall then have for the composition of these substances the following expressions:

Starch . . . =12 C+10 aqua.
Cane sugar . =12 C+10 aqua+1 aqua.
Gum . . . =12 C+10 aqua+1 aqua
Sugar of milk . =12 C+10 aqua+2 aqua.
Grape sugar . =12 C+10 aqua+4 aqua.

For the same number of equivalents of carbon, starch contains 10 equivalents, cane sugar and gum 11 equivalents, sugar of milk 12 equivalents, and grape-sugar 14 equivalents of water, or the elements of water.

XIV. In these different substances, some one of which is never wanting in the food of the graminivora, there is added to the nitrogenized constituents of this food, to the vegetable albumen, fibrine, and caseine, from which their blood is formed, strictly speaking, only a certain excess of carbon, which the animal organism cannot possibly employ to produce fibrine or albumen, because the nitrogenized constituents of the food already contain the carbon necessary for the production of blood, and because the blood in the body of the carnivora is formed without the aid of this excess of carbon.

The function formed in the vital process of the graminivora by these substances (sugar, gum, &c.) is indicated in a very clear and convincing manner, when we take into consideration the very small relative amount of the carbon which these animals consume in the nitrogenized constituents of their food, which bears no proportion whatever to the oxygen absorbed through the skin and lungs.

A horse, for example, can be kept in a perfectly good condition, if he obtains as food 15 lbs. of hay and 4½ lbs. of oats daily. If we now calculate the whole amount of nitrogen in these matters, as ascertained by analysis (1·5 per cent. in the hay, 2·2 per cent. in the oats,) (15) in the form of blood, that is, as fibrine and albumen, with the due proportion of water in blood, (80 per cent.,) the horse receives daily no more than 4½ oz. of nitrogen, corresponding to about 8 lbs. of blood. But along with this nitrogen, that is, combined with it in the form of fibrine or albumen, the animal receives only about 14½ oz. of carbon. Only about 8 oz. of this can be employed to support respiration, for with the nitrogen expelled in the urine there are combined, in the form of urea, 3 oz., and in the form of hippuric acid, 3½ oz. of carbon.

Without going further into the calculation it will readily be admitted, that the volume of air inspired and expired by a horse, the quantity of oxygen consumed, and, as a necessary consequence, the amount of carbonic acid given out by the animal, is much greater than in the respiratory process in man. But an adult man consumes daily about 14 oz. of carbon, and the determination of Boussingault, according to which a horse expires 79 oz. daily, cannot be very far from the truth.

In the nitrogenized constituents of his food, therefore, the horse receives rather less than the fifth part of the carbon which his organism requires for the support of the respiratory process; and we see that the wisdom of the Creator has added to his food the ⅘ths which are wanting, in various forms, as, starch, sugar, &c. with which the animal must be supplied, or his organism will be destroyed by the action of the oxygen.

It is obvious, that in the system of the graminivora, whose food contains so small a proportion, relatively, of the constituents of blood, the process of metamorphosis in existing tissues, and consequently their restoration or reproduction, must go on far less rapidly than in the carnivora. Were this not the case, a vegetation a thousand times more luxuriant than the actual one would not suffice for their nourishment. Sugar, gum, and starch would no longer be necessary to support life in these animals, because, in that case, the products of the waste, or metamorphosis of the organized tissues, would contain enough of carbon to support the respiratory process.

Man, when confined to animal food, requires for his support and nourishment extensive sources of food, even more widely extended than the lion and tiger, because, when he has the opportunity, he kills without eating.

A nation of hunters, on a limited space, is utterly incapable of increasing its numbers beyond a certain point, which is soon attained. The carbon necessary for respiration must be obtained from the animals, of which only a limited number can live on the space supposed. These animals collect from the plants the constituents of their organs and of their blood, and yield them, in turn, to the savages who live by the chase alone. They, again, receive this food unaccompanied by those compounds, destitute of nitrogen, which, during the life of the animals, served to support the respiratory process. In such men, confined to an animal diet, it is the carbon of the flesh and of the blood which must take the place of starch and sugar.

But 15 lbs. of flesh contain not more carbon than 4 lbs. of starch, (16) and while the savage with one animal and an equal weight of starch could maintain life and health for a certain number of days, he would be compelled, if confined to flesh, in order to procure the carbon necessary for respiration, during the same time, to consume five such animals.

It is easy to see, from these considerations, how close the connexion is between agriculture and the multiplication of the human species. The cultivation of our crops has ultimately no other object than the production of a maximum of those substances which are adapted for assimilation and respiration, in the smallest possible space. Grain and other nutritious vegetables yield us, not only in starch, sugar, and gum, the carbon which protects our organs from the action of oxygen, and produces in the organism the heat which is essential to life, but also in the form of vegetable fibrine, albumen, and caseine, our blood, from which the other parts of our body are developed.

Man, when confined to animal food, respires, like the carnivora, at the expense of the matters produced by the metamorphosis of organized tissues; and, just as the lion, tiger, hyæna, in the cages of a menagerie, are compelled to accelerate the waste of the organized tissues by incessant motion, in order to furnish the matter necessary for respiration, so the savage, for the very same object, is forced to make the most laborious exertions and go through a vast amount of muscular exercise. He is compelled to consume force merely in order to supply matter for respiration.

Cultivation is the economy of force. Science teaches us the simplest means of obtaining the greatest effect with the smallest expenditure of power, and with given means to produce a maximum of force. The unprofitable exertion of power, the waste of force in agriculture, in other branches of industry, in science, or in social economy, is characteristic of the savage state, or of the want of cultivation.

XV. A comparison of the urine of the carnivora with that of the graminivora shows very clearly, that the process of metamorphosis in the tissues is different, both in form and in rapidity, in the two classes of animals.

The urine of carnivorous animals is acid, and contains alkaline bases united with uric, phosphoric, and sulphuric acids. We know perfectly the source of the two latter acids. All the tissues, with the exception of cellular tissue and membrane, contain phosphoric acid and sulphur, which latter element is converted into sulphuric acid by the oxygen of the arterial blood. In the various fluids of the body there are only traces of phosphates or sulphates, except in the urine, where both are found in abundance. It is plain that they are derived from the metamorphosed tissues; they enter into the venous blood in the form of soluble salts, and are separated from it in its passage through the kidneys.

The urine of the graminivora is alkaline; it contains alkaline carbonates in abundance, and so small a portion of alkaline phosphates as to have been overlooked by most observers.

The deficiency or absence of alkaline phosphates in the urine of the graminivora, obviously indicates the slowness with which the tissues in this class of animals are metamorphosed; for if we assume that a horse consumes a quantity of vegetable fibrine and albumen corresponding to the amount of nitrogen in his daily food (about 4½ oz.,) and that the quantity of tissue metamorphosed is equal to that newly formed, then the quantity of phosphoric acid which on these suppositions would exist in the urine is not so small as not to be easily detected by analysis in the daily secretion of urine (3 lbs. according to Boussingault;) for it would amount to 0.8 per cent. But, as above stated, most observers have been unable to detect phosphoric acid in the urine of the horse.

Hence it is obvious that the phosphoric acid which in consequence of the metamorphosis of tissues is produced in the form of soluble alkaline phosphates, must re-enter the circulation in this class of animals. It is there employed in forming brain and nervous matter, to which it is essential, and also, no doubt, in contributing to the supply of the earthy part of the bones. It is probable, however, that the greater part of the earth of bones is obtained by the direct assimilation of phosphate of lime, while the soluble phosphates are better adapted for the production of nervous matter.

In the graminivora, therefore, whose food contains so small a proportion of phosphorus or of phosphates, the organism collects all the soluble phosphates produced by the metamorphosis of tissues, and employs them for the developement of the bones and of the phosphorised constituents of the brain; the organs of excretion do not separate these salts from the blood. The phosphoric acid, which, by the change of matter, is separated in the uncombined state, is not expelled from the body as phosphate of soda; but we find it in the solid excrements in the form of insoluble earthy phosphates.

XVI. If we now compare the capacity for increase of mass, the assimilative power in the graminivora and carnivora, the commonest observations indicate a very marked difference.

A spider, which sucks with extreme voracity the blood of the first fly, is not disturbed or excited by a second or third. A cat will eat the first, and perhaps the second mouse presented to her, but even if she kills a third, she does not devour it. Exactly similar observations have been made in regard to lions and tigers, which only devour their prey when urged by hunger. Carnivorous animals, indeed, require less food for their mere support, because their skin is destitute of perspiratory pores, and because they consequently lose, for equal bulks, much less heat than graminivorous animals, which are compelled to restore the lost heat by means of food adapted for respiration.

How different is the energy and intensity of vegetative life in the graminivora. A cow, or a sheep, in the meadow, eats, almost without interruption, as long as the sun is above the horizon. Their system possesses the power of converting into organized tissues all the food they devour beyond the quantity required for merely supplying the waste of their bodies.

All the excess of blood produced is converted into cellular and muscular tissue; the graminivorous animal becomes fleshy and plump, while the flesh of the carnivorous animal is always tough and sinewy.

If we consider the case of a stag, a roe-deer, or a hare, animals which consume the same food as cattle and sheep, it is evident that, when well supplied with food, their growth in size, their fattening, must depend on the quantity of vegetable albumen, fibrine, or caseine, which they consume. With free and unimpeded motion and exercise, enough of oxygen is absorbed to consume the carbon of the gum, sugar, starch, and of all similar soluble constituents of their food.

But all this is very differently arranged in our domestic animals, when with an abundant supply of food, we check the processes of cooling and exhalation, as we do when we feed them in stables, where free motion is impossible.

The stall-fed animal eats, and reposes merely for digestion. It devours in the shape of nitrogenized compounds far more food than is required for reproduction, or the supply of waste alone; and at the same time it eats far more of substances devoid of nitrogen than is necessary merely to support respiration and to keep up animal heat. Want of exercise and diminished cooling are equivalent to a deficient supply of oxygen; for when these circumstances occur, the animal absorbs much less oxygen than is required to convert into carbonic acid the carbon of the substances destined for respiration. Only a small part of the excess of carbon thus occasioned is expelled from the body in the horse and ox, in the form of hippuric acid; and all the remainder is employed in the production of a substance which, in the normal state, only occurs in small quantity as a constituent of the nerves and brain. This substance is *fat*.

In the normal condition, as to exercise and labour, the urine of the horse and ox contains benzoic acid (with 14 equivalents of carbon;) but as soon as the animal is kept quiet in the stable, the urine contains hippuric acid, (with 18 equivalents of carbon.)

The flesh of wild animals is devoid of fat; while that of stall-fed animals is covered with that substance. When the fattened animal is allowed to move more freely in the air, or compelled to draw heavy burdens, the fat again disappears.

It is evident, therefore, that the formation of fat in the animal body is the result of a want of due proportion between the food taken into the stomach and the oxygen absorbed by the lungs and the skin.

A pig, when fed with highly nitrogenized food, becomes full of flesh; when fed with potatoes (starch) it acquires little flesh, but a thick layer of fat. The milk of a cow, when stall-fed, is very rich in butter, but in the meadow is found to contain more caseine, and in the same proportion less butter and sugar of milk. In the human female, beer, and farinaceous diet increase the proportion of butter in the milk; an animal diet yields less milk, but it is richer in caseine.

If we reflect, that in the entire class of carnivora, the food of which contains no substance devoid of nitrogen except fat, the production of fat in the body is utterly insignificant; that even in these animals, as in dogs and cats, it increases as soon as they live on a mixed diet; and that we can increase the formation of fat in other domestic animals at pleasure, but only by means of food containing no nitrogen; we can hardly entertain a doubt that such food, in its various forms of starch, sugar, &c., is closely connected with the production of fat.

In the natural course of scientific research, we draw conclusions from the food in regard to the tissues or substances formed from it; from the nitrogenized constituents of plants we draw certain inferences as to the nitrogenized constituents of the blood; and it is quite in accordance with this, the natural method, that we should seek to establish the relations of those parts of our food which are devoid of nitrogen and those parts of the body which contain none of that element. It is impossible to overlook the very intimate connexion between them.

If we compare the composition of sugar of milk, of starch, and of the other varieties of sugar, with that of mutton and beef suet and of human fat, we find that in all of them the proportion of carbon to hydrogen is the same, and that they only differ in that of oxygen.

According to the analyses of Chevreul, mutton fat, human fat, and hogs' lard, contain 29 per cent. of carbon to 11.1, 11.4, and 11.7 per cent. of hydrogen respectively. (16)

Starch contains 44.91 carbon to 6.11 hydrogen.

Gum and sugar 42.58 carbon to 6.37 hydrogen. (17)

It is obvious that these numbers, representing the relative proportions of carbon and hydrogen in starch, gum, and sugar, are in the same ratio as the carbon and hydrogen in the different kinds of fat; for

$$44{\cdot}91 : 6{\cdot}11 = 79 : 10{\cdot}99$$
$$42{\cdot}58 : 6{\cdot}37 = 79 : 11{\cdot}80$$

From which it follows, that sugar, starch and gum, by the mere separation of a part of their oxygen, may pass into fat, or at least into a substance having exactly the composition of fat. If from the formula of starch, $C^{12}H^{10}O^{10}$, we take 9 equivalents of oxygen, there will remain in 100 parts—

C^{12}	- - -	79·4
H^{10}	- - -	10·8
O	- - -	9·8

The empirical formula of fat which comes nearest to this is $C^{11}H^{10}O$, which gives in 100 parts—

C^{11}	- - -	78·9
H^{10}	- - -	11·6
O	- -	9·5

According to this formula, an equivalent of starch, in order to be changed into fat would lose 1 equivalent of carbonic acid, CO^2, and 7 equivalents of oxygen.

Now the composition of all saponifiable fatty bodies agrees very closely with one or other of these two formulæ.

If from 3 equivalents of sugar of milk, $3C^{12}H^{12}O^{12} = C^{36}H^{36}O^{36}$, we take away four equivalents of water and 31 of oxygen, there will remain $C^{36}H^{22}O$, a formula which accurately represents the composition of cho lesterine, the fat of bile. (18.)

Whatever views we may entertain regarding the origin of the fatty constituents of the body, this much at least is undeniable, that the herbs and roots consumed by the cow contain no butter; that in hay or the other fodder of oxen no beef suet exists; that no hogs' lard can be found in the potato refuse given to swine; and that the food of geese or fowls contains no goose fat or capon fat. The masses of fat found in the bodies of these animals are formed in their organism; and when the full value of this fact is recognised, it entitles us to conclude that a certain quantity of oxygen, in some form or other, separates from the constituents of their food; for without such a separation of oxygen, no fat could possibly be formed from any one of these substances.

The chemical analysis of the constituents of the food of the graminivora shows in the clearest manner that they contain carbon and oxygen in certain proportions; which, when reduced to equivalents, yield the following series:—

In vegetable fibrine, albumen, and caseine, there are contained, for

	120 eq. carbon,	36 eq. oxygen.
In starch	120	100
In cane sugar	120	110
In gum	120	110
In sugar of milk	120	120
In grape sugar	120	140

Now in all fatty bodies there are contained, on an average—

For - 120 eq. carb. only 10 eq. oxygen.

Since the carbon of the fatty constituents of the animal body is derived from the food seeing that there is no other source whence it can be derived, it is obvious, if we suppose fat to be formed from albumen, fibrine, or caseine, that, for every 120 equivalents of carbon deposited as fat, 26 equivalents of oxygen must be separated from the elements of these substances; and further, if we conceive fat to be formed from starch, sugar, or sugar of milk, that for the same amount of carbon there must be separated 90, 100, and 110 equivalents of oxygen from these compounds respectively.

There is, therefore, but one way in which the formation of fat in the animal body is possible, and this is absolutely the same in which its formation in plants takes place; it is a separation of oxygen from the elements of the food.

The carbon which we find deposited in the seeds and fruits of vegetables, in the form of oil and fat, was previously a constituent of the atmosphere, and was absorbed by the plant as carbonic acid. Its conversion into fat was accomplished under the influence of light, by the vital force of the vegetable; and the greater part of the oxygen of this carbonic acid was returned to the atmosphere as oxygen gas.*

In contradistinction to this phenomenon of vitality in plants, we know that the animal system absorbs oxygen from the atmosphere, and that this oxygen is again given out in combination with carbon or hydrogen; we know, that in the formation of carbonic acid and water, the heat necessary to sustain the constant temperature of the body is produced, and that a process of oxidation is the only source of animal heat.

Whether fat be formed by the decomposition of fibrine and albumen, the chief constituents of blood, or by that of starch, sugar, or gum, this decomposition must be accompanied by the separation of oxygen from the elements of these compounds. But this oxygen is not given out in the free state, because it meets in the organism with substances possessing the property of entering into combination with it. In fact, it is given out in the same forms as that which is absorbed from the atmosphere by the skin and lungs.

It is easy to see, from the above considerations, that a very remarkable connexion exists between the formation of fat and the respiratory process.

XVIII. The abnormal condition, which causes the deposit of fat in the animal body, depends, as was formerly stated, on a disproportion between the quantity of carbon in the food and that of oxygen, absorbed by the skin and lungs. In the normal condition, the quantity of carbon given out is exactly equal to that which is taken in the food, and the body acquires no increase of weight from the accumulation of substances containing much carbon and no nitrogen.

If we increase the supply of highly carbonized food, then the normal state can only be preserved on the condition that, by exercise and labor, the waste of the body is increased, and the supply of oxygen augmented in the same proportion.

The production of fat is always a consequence of a deficient supply of oxygen, for oxygen is absolutely indispensable for the dissipation of the excess of carbon in the food. This excess of carbon, deposited in the form of fat, is never seen in the Bedouin or in the Arab of the desert, who exhibits with pride to the traveller his lean, muscular, sinewy limbs, altogether free from fat; but in prisons and jails it appears as a puffiness in the inmates, fed, as they are, on a poor and scanty diet; it appears in the sedentary females of oriental countries; and finally, it is produced under the well known conditions of the fattening of domestic animals.

The formation of fat depends on a deficiency of oxygen; but in this process, in the formation of fat itself, there is opened up a new source of oxygen, a new cause of animal heat.

The oxygen set free in the formation of fat is given out in combination with carbon or hydrogen; and whether this carbon and hydrogen proceed from the substance that yields the oxygen, or from other compounds, still there must have been generated by this formation of carbonic acid or water as much heat as if an equal weight of carbon or hydrogen had been burned in air or in oxygen gas.

If we suppose that from 2 equivalents of starch 18 equivalents of oxygen are disengaged, and that these 18 equivalents of oxygen combine with 9 equivalents of carbon, from the bile, for example, no one can doubt that, in this case, exactly as much heat must be developed, as if these 9 equivalents of carbon had been directly burned. In this form, therefore, the disengagement of heat as a consequence of the formation of fat would be undeniable; and it could only be considered hypothetical, on the supposition that carbon and oxygen were disengaged from one and the same substance, in the proportions to yield carbonic acid.

If, for example, we suppose that from 2 atoms of starch, $C^{24}H^{20}O^{20}$, the elements of 9 equivalents of carbonic acid are separated, there will remain a compound containing, for 15 equivalents of carbon, 20 of hydrogen and 2 of oxygen; for

$$C^{24}H^{20}O^{20} = C^{9}O^{18} + C^{15}H^{20}O^{2}.$$

Or, if we assume that oxygen is separated from starch in the form both of carbonic acid and water, then, after subtracting the elements of 6 equivalents of water and 6 of carbonic acid, there would remain the compound $C^{18}H^{14}O^{2}$; for

$$C^{24}H^{20}O^{20} = C^{6}O^{12} + H^{6}O^{6} + C^{18}H^{14}O^{2}.$$

Assuming, then, the separation of oxygen in either of these forms, it remains to be decided whether the carbonic acid and water given off were contained, *as such*, in the starch, or not.

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* See Appendix, No. 19, on the formation of wax and honey by the bee.

If they were ready formed in the starch, the separation might occur without the disengagement of heat; but if the carbon and hydrogen were present in any other form in the starch, (or in the compound from which the fat was produced,) it is obvious that a change in the arrangement of the atoms must have occurred, in consequence of which the atoms of the carbon and of the hydrogen have united with those of the oxygen, to form carbonic acid and water.

Now, so far as chemical researches have gone, our knowledge of the constitution of starch, and of the varieties of sugar, will justify no other conclusion than this, that these substances contain *no ready formed carbonic acid*.

We are acquainted with a large number of processes of metamorphosis of a similar kind, in which the elements of carbonic acid and water are separated from certain preexisting compounds; and we know with certainty that all these processes are accompanied by a disengagement of heat, exactly as if the carbon and hydrogen combined directly with oxygen.

Such a disengagement of carbonic acid, for example, occurs in all processes of fermentation or putrefaction, which are, without exception, accompanied with a generation of heat.

In the fermentation of a saccharine solution, in consequence of a new arrangement of the elements of the sugar, a certain part of its carbon and oxygen unite to form carbonic acid, which separates as gas; and as another result of this decomposition, we obtain a volatile combustible liquid, containing little oxygen, namely, alcohol.

If we add to 2 equivalents of sugar the elements of 12 equivalents of water, and subtract from the sum of the atoms 24 equivalents of oxygen, there remain 6 equivalents of alcohol.

$$(C^{24}H^{24}O^{24} + H^{12}O^{12}) - O^{24} = C^{24}H^{36}O^{12} = 6 \text{ eq. alcohol.}$$

These 24 equivalents of oxygen suffice to oxidize completely a third equivalent of sugar—that is, to convert its carbon into carbonic acid and its hydrogen into water, and by this oxidation we recover the 12 equivalents of water supposed to be added in the former part of the process, exactly as if this water had taken no share in it.

$$C^{12}H^{12}O^{12} + O^{24} = 12CO^{2} + 12HO.$$

According to the ordinary view, 12 equivalents of carbonic acid separate from 3 of sugar, yielding 6 of alcohol—that is, exactly the same amount of these products as if two-thirds of the sugar had yielded oxygen to the remaining third, so as completely to oxidize its elements.

$$C^{36}H^{36}O^{36} = C^{24}H^{36}O^{12} + 12CO^{2}.*$$

By a comparison of these two methods of representing the same change, it will easily be seen that the division or splitting of a compound like sugar into carbonic acid, on the one hand, and a compound containing a little oxygen on the other, is in its results perfectly equivalent to a separation of oxygen from a certain portion of the compound, and the oxidation or combustion of another portion of it at the expense of this oxygen.

It is well known that the temperature of a fermenting liquid rises; and if we assume that a hogshead of wort, holding 1,200 litres = 2,400 lbs., French weight, contains 16 per cent. of sugar, in all 384 lbs., then, during the fermentation of this sugar, an amount of heat must be generated equal to that which would be produced by the combustion of 51 lbs. of carbon.

This is equal to a quantity of heat by which every pound of the liquid might be heated by 297·9°; that is, supposing the decomposition of the sugar to occur in a period of time too short to be measured. This is well known not to be the case; the fermentation lasts five or six days, and each pound of liquid receives the 297·9 degrees of heat during a period of 120 hours. In each hour there is, therefore, set free an amount of heat capable of raising the temperature of each pound of liquid 1·4 degree; a rise of temperature which is very powerfully counteracted by external cooling and by the vaporization of alcohol and water.

The formation of fat, like other analogous phenomena in which oxygen is separated in the form of carbonic acid, is consequently accompanied by a disengagement of heat. This change supplies to the animal body a certain proportion of the oxygen indispensable to the vital processes; and this especially in those cases in which the oxygen absorbed by the skin and lungs is not sufficient to convert into carbonic acid the whole of the carbon adapted for this combination.

This excess of carbon, as it cannot be employed to form a part of any organ, is deposited in the cellular tissue in the form of tallow or oil.

At every period of animal life, when there occurs a disproportion between the carbon of the food and the inspired oxygen, the latter being deficient, fat must be formed. Oxygen separates from existing compounds, and this oxygen is given out as carbonic acid or water. The heat generated in the formation of these two products contributes to keep up the temperature of the body.

Every pound of carbon which obtains the oxygen necessary to convert it into carbonic acid from substances which thereby pass into fat, must disengage as much heat as would raise the temperature of 200 lbs. of water by 70°,—that is, from 32° to 102°.

Thus, in the formation of fat, the vital force possesses a means of counteracting a deficiency in the supply of oxygen, and consequently in that of the heat indispensable for the vital process.

Experience teaches us that in poultry, the maximum of fat is obtained by tying the feet, and by a medium temperature. These animals in such circumstances may be compared to a plant possessing in the highest degree the power of converting all food into parts of its own structure. The excess of the constituents of blood forms flesh and other organized tissues, while that of starch, sugar, &c., is converted into fat. When animals are fattened on food destitute of nitrogen, only certain parts of their structure increase in size. Thus, in a goose, fattened in the method above alluded to, the liver becomes three or four times larger than in the same animal, when well fed with free motion, while we cannot say that the organized structure of the liver is thereby increased. The liver of a goose fed in the ordinary way is firm and elastic; that of the imprisoned animal is soft and spongy. The difference consists in a greater or less expansion of its cells which are filled with fat.

In some diseases, the starch, sugar, &c., of the food obviously do not undergo the changes which enable them to assist in respiration, and consequently to be converted into fat. Thus, in diabetes mellitus, the starch is only converted into grape sugar, which is expelled from the body without further change.

In other diseases, as for example in inflammation of the liver, we find the blood loaded with fat and oil; and in the composition of the bile there is nothing at all inconsistent with the supposition that some of its constituents may be transformed into fat.

XIX. According to what has been laid down in the preceding pages, the substances of which the food of man is composed may be divided into two classes; into *nitrogenized* and *non-nitrogenized*. The former are capable of conversion into blood; the latter incapable of this transformation.

Out of those substances which are adapted to the formation of blood are formed all the organized tissues. The other class of substances, in the normal state of health, serve to support the process of respiration. The former may be called the *plastic elements of nutrition;* the latter, *elements of respiration.*

Among the former we reckon—

Vegetable fibrine.
Vegetable albumen.
Vegetable caseine.
Animal flesh.
Animal blood.

Among the elements of respiration in our food, are—

Fat.
Starch.
Gum.
Cane Sugar.
Grape Sugar.
Sugar of milk.
Pectine.
Bassorine.
Wine.
Beer.
Spirits.

XX. The most recent and exact researches have established as a universal fact, to which nothing yet known is opposed, that the nitrogenized constituents of vegetable food have a composition identical with that of the constituents of the blood.

No nitrogenized compound, the composition of which differs from that of fibrine, albumen, and caseine, is capable of supporting the vital process in animals.

The animal organism unquestionably possesses the power of forming, from the constituents of its blood, the substance of its membranes and cellular tissue, of the nerves and brain, of the organic part of cartilages and bones. But the blood must be supplied to it ready formed in every thing but its form—that is, in its chemical composition. If this be not done, a period is rapidly put to the formation of blood, and consequently to life.

This consideration enables us easily to explain how it happens that the tissues yielding gelatine or chondrine, as, for example, the gelatine of skin or of bones, are not adapted for the support of the vital process; for their composition is different from that of fibrine or albumen. It is obvious that this means nothing more than that those parts of the animal organism which form the blood do not possess the power of effecting a transformation in the arrangement of the elements of gelatine, or of those tissues which contain it. The gelatinous tissues, the gelatine of the bones, the membranes, the cells, and the skin, suffer, in the animal body, under the influence of oxygen and moisture, a progressive alteration; a part of these tissues is separated, and must be restored from the blood; but this alteration and restoration is obviously confined within very narrow limits.

While, in the body of a starving or sick individual, the fat disappears, and the muscular tissue takes once more the form of blood, we find that the tendons and membranes retain their natural condition; the limbs of the dead body retain their connexions, which depend on the gelatinous tissues.

On the other hand, we see that the gelatine of bones devoured by a dog entirely disappears, while only the bone earth is found in his excrements. The same is true of man, when fed on food rich in gelatine, as, for example, strong soup. The gelatine is not to be found either in the urine or in the fæces, and consequently must have undergone a change, and must have served some purpose in the animal economy. It is clear, that the gelatine must be expelled from the body in a form different from that in which it was introduced as food.

When we consider the transformation of the albumen of the blood into a part of an organ composed of fibrine, the identity in composition of the two substances renders the change easily conceivable. Indeed we find the change of a dissolved substance into an insoluble organ of vitality, chemically speaking, natural and easily explained, or account of this very identity of composition. Hence the opinion is not unworthy of a closer investigation, that gelatine, when taken in the dissolved state, is again converted, in the body, into cellular tissue, membrane and cartilage; that it may serve for the reproduction of such parts of these tissues as have been wasted, and for their growth.

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* For an explanation of the formulæ and equations employed, see the Introduction to the Appendix.

And when the powers of nutrition in the whole body are affected by a change of the health, then, even should the power of forming blood remain the same, the organic force by which the constituents of the blood are transformed into cellular tissue and membranes must necessarily be enfeebled by sickness. In the sick man, the intensity of the vital force, its power to produce metamorphoses, must be diminished as well in the stomach as in all other parts of the body. In this condition, the uniform experience of practical physicians shows that gelatinous matters in a dissolved state exercise a most decided influence on the state of the health. Given in a form adapted for assimilation, they serve to husband the vital force, just as may be done, in the case of the stomach, by due preparation of the food in general. Brittleness in the bones of graminivorous animals is clearly owing to a weakness in those parts of the organism whose function it is to convert the constituents of the blood into cellular tissue and membrane; and if we can trust to the reports of physicians who have resided in the East, the Turkish women, in their diet of rice, and in the frequent use of enemata of strong soup, have united the conditions necessary for the formation both of cellular tissue and of fat.

PART II.

THE METAMORPHOSIS OF TISSUES.

1. THE absolute identity of composition in the chief constituents of blood and the nitrogenized compounds in vegetable food would, some years ago, have furnished a plausible reason for denying the accuracy of the chemical analysis leading to such a result. At that period, experiment had not as yet demonstrated the existence of numerous compounds, both containing nitrogen and devoid of that element, which with the greatest diversity in external characters, yet possess the very same composition in 100 parts; nay, many of which even contain the same absolute amount of equivalents of each element. Such examples are now very frequent, and are known by the names of *isomeric* and *polymeric* compounds.

2. Cyanuric acid, for example, is a nitrogenized compound which crystallizes in beautiful transparent octahedrons, easily soluble in water and in acids, and very permanent. Cyamelide is a second body, absolutely insoluble in water and acids, white and opaque like porcelain or magnesia. Hydrated cyanic acid is a third compound, which is a liquid more volatile than pure acetic acid, which blisters the skin, and cannot be brought in contact with water without being instantaneously resolved into new products. These three substances not only yield, on analysis, absolutely the same relative weights of the same elements, but they may be converted and reconverted into one another, even in hermetically closed vessels—that is, without the aid of any foreign matter. (See Appendix, 21.) Again, among those substances which contain no nitrogen, we have aldehyde, a combustible liquid miscible with water, which boils at the temperature of the hand, attracts oxygen from the atmosphere with avidity, and is thereby changed into acetic acid. This compound cannot be preserved, even in close vessels; for after some hours or days, its consistence, its volatility, and its power of absorbing oxygen, all are changed. It deposits long, hard, needle-shaped crystals, which at 212° are not volatilized, and the supernatant liquid is no longer aldehyde. It now boils at 140°, cannot be mixed with water, and when cooled to a moderate degree crystallizes in a form like ice. Nevertheless, analysis has proved, that these three bodies, so different in their characters, are identical in composition. (21.)

3. A similar group of three occurs in the case of albumen, fibrine, and caseine. They differ in external character, but contain exactly the same proportions of organic elements.

When animal albumen, fibrine, and caseine are dissolved in a moderately strong solution of caustic potash, and the solution is exposed for some time to a high temperature, these substances are decomposed. The addition of acetic acid to the solution causes, in all three, the separation of a gelatinous translucent precipitate, which has exactly the same characters and composition, from whichever of the three substances above mentioned it has been obtained.

Mulder, to whom we owe the discovery of this compound, found, by exact and careful analysis, that it contains the same organic elements, and exactly in the same proportion, as the animal matters from which it is prepared; insomuch, that if we deduct from the analysis of albumen, fibrine, and caseine, the ashes they yield when incinerated, as well as the sulphur and phosphorus they contain, and then calculate the remainder for 100 parts, we obtain the same result as in the analysis of the precipitate above described, prepared by potash, which is free from inorganic matter. (22.)

Viewed in this light, the chief constituents of the blood and the caseine of milk may be regarded as compounds of phosphates and other salts, and of sulphur and phosphorus, with a compound of carbon, nitrogen, hydrogen, and oxygen, in which the relative proportion of these elements is invariable; and this compound may be considered as the commencement and starting point of all other animal tissues, because these are all produced from the blood.

These considerations induced Mulder to give to this product of the decomposition of albumen, &c., by potash, the name of *proteine* (from πρωτεύω, "I take the first rank.") The blood, or the constituents of the blood, are consequently compounds of this proteine with variable proportions of inorganic substances.

Mulder further ascertained, that the insoluble nitrogenized constituent of wheat flour (vegetable fibrine,) when treated with potash, yields the very same product, proteine; and it has recently been proved that vegetable albumen and caseine are acted on by potash precisely as animal albumen and caseine are.

4. As far, therefore, as our researches have gone, it may be laid down as a law, founded on experience, that vegetables produce, in their organism, compounds of proteine; and that out of these compounds of proteine the various tissues and parts of the animal body are developed by the vital force, with the aid of the oxygen of the atmosphere and of the elements of water.*

Now, although it cannot be demonstrated that proteine exists ready formed in these vegetable and animal products, and although the difference in their properties seems to indicate that their elements are not arranged in the same manner, yet the hypothesis of the pre-existence of proteine, as a point of departure in developing and comparing their properties, is exceedingly convenient. At all events it is certain that the elements of these compounds assume the same arrangements when acted on by potash at a high temperature.

All the organic nitrogenized constituents of the body, how different soever they may be in composition, are derived from proteine. They are formed from it, by the addition or subtraction of the elements of water or of oxygen, and by resolution into two or more compounds.

5. This proposition must be received as an undeniable truth, when we reflect on the developement of the young animal in the egg of a fowl. The egg can be shown to contain no other nitrogenized compound except albumen. The albumen of the yolk is identical with that of the white; (23) the yolk contains, besides, only a yellow fat, in which cholesterine and iron may be detected. Yet we see in the process of incubation, during which no food and no foreign matter, except the oxygen of the air, is introduced, or can take part in the developement of the animal, that out of the albumen, feathers, claws, globules of the blood, fibrine, membrane and cellular tissue, arteries and veins, are produced. The fat of the yolk may have contributed, to a certain extent, to the formation of the nerves and brain; but the carbon of this fat cannot have been employed to produce the organized tissues in which vitality resides, because the albumen of the white and of the yolk already contains, for the quantity of nitrogen present, exactly the proportion of carbon required for the formation of these tissues.

6. The true starting-point for all the tissues is, consequently, albumen; all nitrogenized articles of food, whether derived from the animal or from the vegetable kingdom, are converted into albumen before they can take part in the process of nutrition.

All the food consumed by an animal becomes in the stomach soluble, and capable of entering into the circulation. In the process by which this solution is effected, only one fluid, besides the oxygen of the air, takes a part; it is that which is secreted by the lining membrane of the stomach.

The most decisive experiments of physiologists have shown that the process of chymification is independent of the vital force; that it takes place in virtue of a purely chemical action, exactly similar to those processes of decomposition or transformation which are known as putrefaction, fermentation or decay (eremacausis).

7. When expressed in the simplest form, fermentation, or putrefaction, may be described as a process of transformation—that is, a new arrangement of the elementary particles, or atoms, of a compound, yielding two or more new groups or compounds, and caused by contact with other substances, the elementary particles of which are themselves in a state of transformation or decomposition. It is a communication, or an imparting of a state of motion, which the atoms of a body in a state of motion are capable of producing in other bodies, whose elementary particles are held together only by a feeble attraction.

8. Thus the clear gastric juice contains a substance in a state of transformation, by the contact of which with those constituents of the food which, by themselves, are insoluble in water, the latter acquire, in virtue of a new grouping of their atoms, the pro-

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* The experiment of Tiedemann and Gmelin, who found it impossible to sustain the life of geese by means of boiled white of egg, may be easily explained, when we reflect that a graminivorous animal, especially when deprived of free motion, cannot obtain, from the transformation or waste of the tissues alone, enough of carbon for the respiratory process. 2 lbs. of albumen contain only 3½ oz. of carbon, of which, among the last products of transformation, a fourth part is given off in the form of uric acid.

perty of dissolving in that fluid. During digestion, the gastric juice, when separated, is found to contain a free mineral acid, the presence of which checks all further change. That the food is rendered soluble quite independently of the vitality of the digestive organs has been proved by a number of the most beautiful experiments. Food, enclosed in perforated metallic tubes, so that it could not come into contact with the stomach, was found to disappear as rapidly, and to be as perfectly digested, as if the covering had been absent; and fresh gastric juice, out of the body, when boiled white of egg, or muscular fibre, were kept in contact with it for a time at the temperature of the body, caused these substances to lose the solid form and to dissolve in the liquid.

9. It can hardly be doubted that the substance which is present in the gastric juice in a state of change is a product of the transformation of the stomach itself. No substances possess, in so high a degree as those arising from the progressive decomposition of the tissues containing gelatine or chondrine, the property of exciting a change in the arrangement of the elements of other compounds. When the lining membrane of the stomach of any animal, as, for example, that of the calf, is cleaned by continued washing with water, it produces no effect whatever, if brought into contact with a solution of sugar, with milk or other substances. But if the same membrane be exposed for some time to the air, or dried, and then placed in contact with such substances, the sugar is changed, according to the state of decomposition of the animal matter, either into lactic acid, into mannite and mucilage, or into alcohol and carbonic acid; while milk is instantly coagulated. An ordinary animal bladder retains, when dry, all its properties unchanged; but when exposed to air and moisture, it undergoes a change not indicated by any obvious external signs. If, in this state, it be placed in a solution of sugar of milk, that substance is quickly changed into lactic acid.

10. The fresh lining membrane of the stomach of a calf, digested with weak muriatic acid, gives to this fluid no power of dissolving boiled flesh or coagulated white of egg. But if previously allowed to dry, or if left for a time in water, it then yields, to water acidulated with muriatic acid, a substance in minute quantity, the decomposition of which is already commenced, and is completed in the solution. If coagulated albumen be placed in this solution, the state of decomposition is communicated to it, first at the edges, which become translucent, pass into a mucilage, and finally dissolve. The same change gradually affects the whole mass, and at last it is entirely dissolved, with the exception of fatty particles, which render the solution turbid. Oxygen is conveyed to every part of the body by the arterial blood; moisture is every where present; and thus we have united the chief conditions of all transformations in the animal body.

Thus, as in the germination of seeds, the presence of a body in a state of decomposition or transformation, which has been called *diastase*, effects the solution of the starch—that is, its conversion into sugar; so, a product of the metamorphosis of the substance of the stomach, being itself in a state of metamorphosis which is completed in the stomach, effects the dissolution of all such parts of the food as are capable of assuming a soluble form. In certain diseases, there are produced from the starch, sugar, &c., of the food, lactic acid and mucilage. (24.) These are the very same products which we can produce out of sugar by means of membrane in a state of decomposition out of the body; but in a normal state of health, no lactic acid is formed in the stomach.

11. The property possessed by many substances, such as starch and the varieties of sugar, by contact with animal substances in a state of decomposition, to pass into lactic acid, has induced physiologists, without farther inquiry, to assume the fact of the production of lactic acid during digestion and the power which this acid has of dissolving phosphate of lime has led them to ascribe to it the character of a general solvent. But neither Prout nor Braconno could detect lactic acid in the gastric juice, and even Lehmann (see his "Lehrbuch der Physiologischen Chemie," tom. i. p. 285) obtained from the gastric juice of a cat only microscopic crystals, which he took for lactate of zinc, although their chemical character could not be ascertained. The presence of free muriatic acid in the gastric juice, first observed by Prout, has been confirmed by all those chemists who have examined that fluid since. This muriatic acid is obviously derived from common salt, the soda of which plays a very decided part in the conversion of fibrine and caseine into blood.

Muriatic acid yields to no other acid in the power of dissolving bone earth, and even acetic acid, in this respect, is equal to lactic acid. There is consequently no proof of the necessity of lactic acid in the digestive process; and we know with certainty, that in artificial digestion it is not formed. Berzelius indeed has found lactic acid in the blood and flesh of animals; but when his experiments were made, chemists were ignorant of the extraordinary facility and rapidity with which this acid is formed from a number of substances containing its elements, when in contact with animal matter.

In the gastric juice of a dog, Braconnot found, along with free muriatic acid, distinct traces of a salt of iron, which he at first held to be an accidental admixture. But in the gastric juice of a second dog, collected with the utmost care, the iron was again found. (Ann. de Ch. et de Ph. lix. p. 249.

This occurrence of iron is full of significance in regard to the formation of the blood.

12. In the action of the gastric juice on the food, no other element takes a share, except the oxygen of the atmosphere and the elements of water. This oxygen is introduced directly into the stomach. During the mastication of the food, there is secreted into the mouth from organs specially destined to this function, a fluid, the saliva, which possesses the remarkable property of enclosing air in the shape of froth, in a far higher degree than even soapsuds. This air, by means of the saliva, reaches the stomach with the food, and there its oxygen enters into combination, while its nitrogen is given out through the skin and lungs. The longer digestion continues, that is, the greater resistance offered to the solvent action by the food, the more saliva, and consequently the more air enters the stomach. Rumination, in certain graminivorous animals, has plainly for one object a renewed and repeated introduction of oxygen; for a more minute mechanical division of the food only shortens the time required for solution.

The unequal quantities of air which reach the stomach with the saliva in different classes of animals explain the accurate observations made by physiologists, who have established beyond all doubt the fact, that animals give out pure nitrogen through the skin and lungs, in variable quantity. This fact is so much the more important, as it furnishes the most decisive proof, that the nitrogen of the air is applied to no use in the animal economy.

The fact that nitrogen is given out by the skin and lungs, is explained by the property which animal membranes possess of allowing all gases to permeate them, a property which can be shown to exist by the most simple experiments. A bladder, filled with carbonic acid, nitrogen, or hydrogen gas, if tightly closed and suspended in the air, loses in 24 hours the whole of the enclosed gas; by a kind of exchange, it passes outwards into the atmosphere, while its place is occupied by atmospherical air. A portion of intestine, a stomach, or a piece of skin or membrane, acts precisely as the bladder, if filled with any gas. This permeability to gases is a mechanical property, common to all animal tissues; and it is found in the same degree in the living as in the dead tissue.

It is known that in cases of wounds of the lungs a peculiar condition is produced, in which, by the act of inspiration, not only oxygen but atmospherical air, with its whole amount ($\frac{4}{5}$ths) of nitrogen, penetrates into the cells of the lungs. This air is carried by the circulation to every part of the body, so that every part is inflated or puffed up with the air, as with water in dropsy. This state ceases, without pain, as soon as the entrance of the air through the wound is stopped. There can be no doubt that the oxygen of the air, thus accumulated in the cellular tissue, enters into combination, while its nitrogen is expired through the skin and lungs.

Moreover, it is well known that in many graminivorous animals, when the digestive organs have been overloaded with fresh juicy vegetables, these substances undergo in the stomach the same decomposition as they would at the same temperature out of the body. They pass into fermentation and putrefaction, whereby so great a quantity of carbonic acid gas and of inflammable gas is generated, that these organs are enormously distended, sometimes even to bursting. From the structure of their stomach or stomachs, these gases cannot escape through the œsophagus; but in the course of a few hours, the distended body of the animal becomes less swollen, and at the end of twenty-four hours no trace of the gases is left. (25.)

Finally, if we consider the fatal accidents which so frequently occur in wine countries from the drinking of what is called feather-white wine (*der federweisse Wein,*) we can no longer doubt that gases of every kind, whether soluble or insoluble in water, possess the property of permeating animal tissues, as water penetrates unsized paper. This poisonous wine is wine still in a state of fermentation, which is increased by the heat of the stomach. The carbonic acid gas which is disengaged penetrates through the parietes of the stomach, through the diaphragm, and through all the intervening membranes, into the air-cells of the lungs, out of which it displaces the atmospherical air. The patient dies with all the symptoms of asphyxia caused by an irrespirable gas; and the surest proof of the presence of the carbonic acid in the lungs is the fact, that the inhalation of ammonia (which combines with it) is recognized as the best antidote against this kind of poisoning.

The carbonic acid of effervescing wines and of soda-water, when taken into the stomach, or of water saturated with this gas, administered in the form of enema, is given out again through the skin and lungs; and this is equally true of the nitrogen which is introduced into the stomach with the food in the saliva.

No doubt a part of these gases may enter the venous circulation through the absorbent and lymphatic vessels, and thus reach the lungs, where they are exhaled; but the presence of membranes offers not the slightest obstacle to their passing directly into the cavity of the chest. It is, in fact, difficult to suppose that the absorbents and lymphatics have any peculiar tendency to absorb air, nitrogen or hydrogen, and convey these gases into the circulation, since the intestines, the stomach, and all spaces in the body not filled with solid or liquid matters, contain gases, which only quit their position when their volume exceeds a certain point, and which, consequently, are not absorbed.

More especially in reference to nitrogen, we must suppose that it is removed from the stomach by some more direct means, and not by the blood, which fluid must already, in passing through the lungs, have become saturated with that gas, that is, must have absorbed a quantity of it, proportioned to its solvent power, like any other liquid. By the respiratory motions, all the gases which fill the otherwise empty spaces of the body are urged towards the chest; for by the motion of the diaphragm and the expansion of the chest a partial vacuum is produced, in consequence of which air is forced into the chest from all sides by the atmospheric pressure. The equilibrum is, no doubt, restored, for the most part, through the windpipe, but all the gases in the body must, nevertheless, receive an impulse towards the chest. In birds and tortoises these arrangements are reversed. If we assume that a man introduces into the stomach in each minute only $\frac{1}{8}$th of a cubic inch of air with the saliva, this makes in eighteen hours 135 cubic inches; and if $\frac{1}{5}$th be deducted as oxygen, there will still remain 108 cubic inches of nitrogen, which occupy the space of 3 lbs. of water. Now whatever may be the actual amount of the nitrogen thus swallowed, it is certain that the whole of it is given out again by the mouth, nose, and skin; and when we consider the very large quantity of nitrogen found in the intestines of executed criminals by Magendie, as well as the entire absence of oxygen in these organs, (26,) we must assume that air, and consequently nitrogen, enters the stomach by resorption through the skin, and is afterwards exhaled by the lungs.

When animals are made to respire in gases containing no nitrogen, more of that gas is exhaled, because in this case the nitrogen within the body acts towards the external space as if the latter were a vacuum. (See Graham "On the Diffusion of Gases.")

The differences in the amount of expired nitrogen in different classes of animals are thus easily explained; the herbivora swallow with the saliva more air than the carnivora; they expire more nitrogen than the latter,—less when fasting than immediately after taking food.

13. In the same way as muscular fibre, when separated from the body, communicates the state of decomposition existing in its elements to the peroxide of hydrogen, so a certain product, arising by means of the vital process, and in consequence of the transposition of the elements of parts of the stomach and of the other digestive organs, while its own metamorphosis is accomplished in the stomach, acts on the food. The insoluble matters become soluble—they are digested.

It is certainly remarkable, that hard-boiled white of egg, or fibrine, when rendered soluble by certain liquids, by organic acids, or weak alkaline solutions, retain all their properties except the solid form (cohesion) without the slightest change. Their elementary molecules, without doubt assume a new arrangement; they do not, however, separate into two or more groups, but remain united together.

The very same thing occurs in the digestive process; in the normal state, the food only undergoes a change in its state of cohesion, becoming fluid without any other change of properties.

The greatest obstacle to forming a clear conception of the nature of the digestive process, which is here reckoned among those chemical metamorphoses which have been called fermentation and putrefaction, consists in our involuntary recollection of the phenomena which accompany the fermentation of sugar and of animal substances, (putrefaction,) which phenomena we naturally associate with any similar change; but there are numberless cases in which a complete chemical metamorphosis of the elements of a compound occurs without the smallest disengagement of gas, and it is chiefly these which must be borne in mind, if we would acquire a clear and accurate idea of the chemical notion or conception of the digestive process.

All substances which can arrest the phenomena of fermentation and putrefaction in liquids, also arrest digestion when taken into the stomach. The action of the empyreumatic matters in coffee and tobacco smoke, of creosote, of mercurials, &c., &c., is on this account worthy of peculiar attention with reference to dietetics.

The identity in composition of the chief constituents of blood and of the nitrogenized constituents of vegetable food has certainly furnished, in an unexpected manner, an explanation of the fact that putrefying blood, white of egg, flesh, and cheese produce the same effects in a solution of sugar as yeast or ferment; that sugar, in contact with these substances, according to the particular stage of decomposition in which the putrefying matters may be, yields, at one time, alcohol and carbonic acid; at another, lactic acid, mannite, and mucilage. The explanation is simply this, that ferment, or yeast, is nothing but vegetable fibrine, albumen, or caseine in a state of decomposition, these substances having the same composition with the constituents of flesh, blood, or cheese. The putrefaction of these animal matters is a process identical with the metamorphosis of the vegetable matters identical with them; it is a separation or splitting up into new and less complex compounds. And if we consider the transformation of the elements of the animal body (the waste of matter in animals) as a chemical process which goes on under the influence of the vital force, then the putrefaction of animal matters out of the body is a division into simpler compounds, in which the vital force takes no share. The action in both cases is the same, only the products differ. The practice of medicine has furnished the

most beautiful and interesting observations on the action of empyreumatic substances, such as wood, vinegar, creosote, &c., on malignant wounds and ulcers. In such morbid phenomena two actions are going on together; one metamorphosis, which strives to complete itself under the influence of the vital force, and another, independent of that force. The latter is a chemical process, which is entirely suppressed or arrested by empyreumatic substances; and this effect is precisely opposed to the poisonous influence exercised on the organism by putrefying blood when introduced into a fresh wound.

14. The formula $C\ H^{36}\ N^{6}O^{14}$* is that which most accurately expresses the composition of proteine, or the relative proportions of the organic elements in the blood, as ascertained by analysis. Albumen, fibrine, and caseine contain proteine; caseine contains, besides, sulphur, but no phosphorus; albumen and fibrine contain both these substances chemically combined—the former more sulphur than the latter. We cannot directly ascertain in what form the phosphorus exists. But we have decided proof that the sulphur cannot be in the oxidized state. All these substances, when heated with a moderately strong solution of potash, yield the sulphur which we find in the solution as sulphuret of potassium; and on the addition of an acid it is given off as sulphuretted hydrogen. When pure fibrine or ordinary albumen is dissolved in a weak solution of potash, and acetate of lead is added to the solution, in such proportion that the whole of the oxide of lead remains dissolved in the potash, the mixture, if heated to the boiling point, becomes black like ink, and sulphuret of lead is deposited as a fine black powder.

It is extremely probable, that by the action of the alkali the sulphur is removed as sulphuretted hydrogen, the phosphorus as phosphoric or phosphorus acid. Since, in this case, sulphur and phosphorus are eliminated on the one hand, and oxygen and hydrogen on the other, it might be concluded that fibrine and albumen, when analyzed with their sulphur and phosphorus, would yield a larger proportion of oxygen and hydrogen than is found in proteine. But this cannot be shown in the analysis; for fibrine, for example, has been found to contain 0·36 per cent. of sulphur. Assuming, then, that this sulphur is eliminated by the alkali in combination with hydrogen, proteine would yield 0·0225 per cent. less hydrogen than fibrine; instead of the mean amount of 7·062 per cent. of hydrogen, the proteine should yield 7·04 per cent. In like manner, by the elimination of the phosphorus in combination with oxygen, the amount of oxygen in fibrine would be reduced from 22·715—22·00 per cent. to 22·5—21·8 per cent. in proteine. But the limits of error in our analyses are, on an average, beyond $\frac{1}{10}$th per cent. in the hydrogen, and beyond $\frac{4}{10}$ths per cent. in the oxygen; while in the supposed case the difference in the hydrogen would not be greater than $\frac{1}{48}$th per cent.

Finally, if we reflect, that the elimination of oxygen and hydrogen with the sulphur and phosphorus does not exclude the addition of the elements of water, and if we assume that fibrine and albumen, in passing into proteine, do combine with a certain quantity of water, an occurrence which is highly probable, we shall see that there is no probability that the ultimate analysis of these compounds shall ever enable us to decide such questions, or to fix the chemical view of the relation of proteine to albumen, fibrine, or caseine, farther than has been done above.

Some have endeavoured to prove the existence of unoxidized phosphorus in albumen and fibrine from the formation of sulphuret of potassium when they are acted on by potash, supposing the oxygen of the potash to have formed phosphoric acid with the phosphorus; but caseine, which contains no phosphorus, yields sulphuret of potassium, just like the other substances; and here its formation cannot be accounted for, unless we admit the previous production of sulphuretted hydrogen. In the mere boiling of flesh, for the purpose of making soup, sulphuretted hydrogen, as Chevreul has shown, is disengaged.

Moreover, the proportion of sulphur, for the same amount of phosphorus, is not the same in fibrine and albumen, from which no other conclusion can be drawn, but that the formation of sulphuret of potassium has no relation to the presence of phosphorus. Sulphuret of potassium is formed from caseine, which is not supposed to contain any uncombined phosphorus; and it is formed, also, from albumen, which contains only half as much phosphorus as fibrine.

Every attempt to give the true absolute amount of the atoms in fibrine and albumen in a rational formula, in which the sulphur and phosphorus are taken, not in fractions, but in entire equivalents, must be fruitless, because we are absolutely unable to determine with perfect accuracy the exceedingly minute quantities of sulphur and phosphorus in such compounds; and because a variation in the sulphur or phosphorus, smaller in extent than the usual limit of errors of observation, will affect the number of atoms of carbon, hydrogen, or oxygen to the extent of 10 atoms or more.

We must be careful not to deceive ourselves in our expectations of what chemical analysis can do. We know, with certainty, that the numbers representing the relative proportions of the organic elements are the same in albumen and fibrine, and hence we conclude that they have the same composition. This conclusion is not affected by the fact, that we do not know the absolute number of the atoms of their elements, which have united to form the compound atom.

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* For the method of converting this and other formula into proportions per cent., see Appendix.

15. A formula for proteine is nothing more than the nearest and most exact expression in equivalents, of the result of the best analyses; it is a fact established so far, free from doubt, and this alone is, for the present, valuable to us.

If we reflect, that from the albumen and fibrine of the body all the other tissues are derived, it is perfectly clear that this can only occur in two ways. Either certain elements have been added to, or removed from, their constituent parts.

If we now, for example, look for an analytical expression of the composition of cellular tissue, of the tissues yielding gelatine, or tendons, of hair, of horn, &c., in which the number of atoms of carbon is made invariably the same as in albumen and fibrine, we can then see at the first glance, in what way the proportion of the other elements has been altered; but this includes all that physiology requires in order to obtain an insight into the true nature of the formative and nutritive processes in the animal body.

From the researches of Mulder and Scherer we obtain the following empirical formulæ.

Composition of organic tissues.

Albumen . . .	$C^{48}N^{6}H^{36}O^{14}+P+S$*
Fibrine . . .	$C^{48}N^{6}H^{36}O^{14}+P+2S$
Caseine . . .	$C^{48}N^{6}H^{36}O^{14}+S$
Gelatinous tissues, tendons	$C^{48}N^{7.5}H^{41}O^{18}$
Chondrine . . .	$C^{48}N^{6}H^{40}O^{20}$
Hair, horn . . .	$C^{48}N^{7}H^{38}O^{17}$
Arterial membrane .	$C^{48}N^{6}H^{38}O^{16}$

The composition of these formulæ shows, that when proteine passes into chondrine, (the substance of the cartilages of the ribs,) the elements of water, with oxygen, have been added to it; while in the formation of the serous membranes, nitrogen also has entered into combination.

If we represent the formula of proteine, $C^{48}N^{6}H^{36}O^{14}$ by Pr, then nitrogen, hydrogen, and oxygen have been added to it in the form of known compounds, and in the following proportions, in forming the gelatinous tissues, hair, horn, arterial membrane, &c.

	Proteine.	Ammonia.	Water.	Oxygen.
Fibrine, Albumen	Pr			
Arterial Membrane	Pr	.	$+2HO$.	
Chondrine . .	Pr	.	$+4HO$.	$+2O$.
Hair, horn . .	Pr	$+NH^{3}$	. .	$+3O$.
Gelatinous tissues	2Pr	$+3NH^{3}$	$+HO$.	$+7O$.

17. From this general statement it appears that all the tissues of the body contain, for the same amount of carbon, more oxygen than the constituents of blood. During their formation, oxygen, either from the atmosphere or from the elements of water, has been added to the elements of proteine. In hair and gelatinous membrane we observe, farther, an excess of nitrogen and hydrogen, and that in the proportions to form ammonia.

Chemists are not yet agreed on the question, in what manner the elements of sulphate of potash are arranged; it would therefore be going too far, were they to pronounce arterial membrane a hydrate of proteine, chondrine a hydrated oxide of proteine, and hair and membranes compounds of ammonia with oxides of proteine.

The above formulæ express with precision the differences of composition in the chief constituents of the animal body; they show, that for the same amount of carbon the proportion of the other elements varies, and how much more oxygen or nitrogen one compound contains than another.

18. By means of these formulæ we can trace the production of the different compounds from the constituents of blood; but the explanation of their production may take two forms, and we have to decide which of these comes nearest to the truth.

For the same amount of carbon, membranes and the tissues which yield gelatine contain more nitrogen, oxygen, and hydrogen than proteine. It is conceivable that they are formed from albumen by the addition of oxygen, of the elements of water, and of those of ammonia, accompanied by the separation of sulphur and phosphorus; at all events, their composition is entirely different from that of the chief constituents of blood.

The action of caustic alkalies on the tissues yielding gelatine shows distinctly that they no longer contain proteine; that substance cannot in any way be obtained from them; and all the products formed by the action of alkalies on them differ entirely from those produced by the compounds of proteine in the same circumstances. Whether proteine exist, ready formed, in fibrine. albumen, and caseine, or not, it is certain that their elements, under the influence of the alkali, arrange themselves so as to form proteine; but this property is wanting in the elements of the tissues which yield gelatine

The other, and perhaps the more probable explanation of the production of these tissues from proteine, is that which makes it dependent on a separation of carbon.

If we assume the nitrogen of proteine to remain entire in the gelatinous tissue, then the composition of the latter calculated on 6 equivalents of nitrogen, would be represented by the formula, $C^{38}N^{6}H^{32}O^{14}$. This formula approaches most closely to the analysis of Scherer, although it is not an exact expression of his results. A formula corresponding more perfectly to the analysis. is $C^{32}N^{5}H^{27}O^{12}$; or calculated according to Mulder's analysis, $C^{54}N^{9}H^{42}O^{20}$.*

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* The quantities of sulphur and phosphorus here expressed by S and P are not equivalents, but only give the relative proportions of these two elements to each other, as found by analysis.

* The formula $C^{52}N^{8}H^{40}O^{20}$, adopted by Mulder, gives, when reduced to 100 parts, too little nitrogen to be considered an exact expression of his analyses.

According to the first formula, carbon and hydrogen have been separated; according to the two last, a certain proportion of all the elements has been removed

19. We must admit, as the most important result of the study of the composition of gelatinous tissue, and as a point undeniably established, that, although formed from compounds of proteine, it no longer belongs to the series of the compounds of proteine. Its chemical characters and composition justify this conclusion.

No fact is as yet opposed to the law, deduced from observation, that nature has exclusively destined compounds of proteine for the production of blood.

No substance analogous to the tissues yielding gelatine is found in vegetables. The gelatinous substance is not a compound of proteine; it contains no sulphur, no phosphorus, and it contains more nitrogen or less carbon than proteine. The compounds of proteine, under the influence of the vital energy of the organs which form the blood, assume a new form, but are not altered in composition; while these organs, as far as our experience reaches, do not possess the power of producing compounds of proteine, by virtue of any influence, out of substances which contain no proteine. Animals which are fed exclusively with gelatine, the most highly nitrogenized element of the food of carnivora, died with the symptoms of starvation; in short, the gelatinous tissues are incapable of conversion into blood.

But there is no doubt that these tissues are formed from the constituents of the blood; and we can hardly avoid entertaining the supposition, that the fibrine of venous blood, in becoming arterial fibrine, passes through the first stage of conversion into gelatinous tissue. We cannot, with much probability, ascribe to membranes and tendons the power of forming themselves out of matters brought by the blood; for how could any matter become a portion of the cellular tissue, for example, by virtue of a force which has as yet no organ? An already existing cell may possess the power of reproducing or of multiplying itself, but in both cases the presence of a substance identical in composition with cellular tissue is essential. Such matters are formed in the organism, and nothing can be better fitted for their production than the substance of the cells and membranes which exist in animal food, and become soluble in the stomach during digestion, or which are taken by man in a soluble form.

20. In the following pages I offer to the reader an attempt to develope analytically the principal metamorphoses which occur in the animal body; and, to preclude all misapprehension, I do this with a distinct protest against all conclusions and deductions which may now or at any subsequent period be derived from it in opposition to the views developed in the preceding part of this work, with which it has no manner of connexion. The results here to be described have surprised me no less than they will others, and have excited in my mind the same doubts as others will conceive; but they are not the creations of fancy, and I give them because I entertain the deep conviction that the method which has led to them is the only one by which we can hope to acquire insight into the nature of the organic processes.

The numberless qualitative investigations of animal matters which are made are equally worthless for physiology and for chemistry, so long as they are not instituted with a well defined object, or to answer a question clearly put.

If we take the letters of a sentence which we wish to decipher, and place them in a line, we advance not a step towards the discovery of their meaning. To resolve an enigma, we must have a perfectly clear conception of the problem. There are many ways to the highest pinnacle of a mountain; but those only can hope to reach it who keep the summit constantly in view. All our labour and all our efforts, if we strive to attain it through a morass, only serve to cover us more completely with mud; our progress is impeded by difficulties of our own creation, and at last even the greatest strength must give way when so absurdly wasted.

21. If it be true that all parts of the body are formed and developed from the blood or the constituents of the blood, that the existing organs at every moment of life are transformed into new compounds under the influence of the oxygen introduced in the blood, then the animal secretions must of necessity contain the products of the metamorphosis of the tissues.

22. If it be further true, that the urine contains those products of metamorphosis which contain the most nitrogen, and the bile those which are richest in carbon, from all the tissues which in the vital process have been transformed into unorganized compounds, it is clear that the elements of the bile and of the urine, added together, must be equal in the relative proportion of these elements to the composition of the blood.

23. The organs are formed from the blood, and contain the elements of the blood; they become transformed into new compounds, with the addition only of oxygen and of water. Hence the relative proportion of carbon and nitrogen must be the same as in the blood.

If then we subtract from the composition of blood the elements of the urine, then the remainder, deducting the oxygen and water which have been added, must give the composition of the bile.

Or if from the elements of the blood, we subtract the elements of the bile, the remainder must give the composition of urate of ammonia, or of urea and carbonic acid.

It will surely appear remarkable that this manner of viewing the subject has led to the true formula of bile, or, to speak more accurately, to the most correct empirical expression of its composition; and has furnished the key to its metamorphoses, under the influence of acids and alkalies, which had previously been sought for in vain.

24. When fresh drawn blood is made to trickle over a plate of silver, heated to 140°, it dries to a red, varnish-like matter, easily reduced to powder. Muscular flesh, free from fat, if dried first in a gentle heat, and then at 212°, yields a brown, pulverizable mass.

The analyses of Playfair and Boeckmann (28) give for flesh (fibrine, albumen, cellular tissue, and nerves) and for blood, as the most exact expression of their numerical results, one and the same formula, namely, $C^{48}N^{6}H^{39}O^{15}$. This may be called the empirical formula of blood.

25. The chief constituent of bile, according to the researches of Demarçay, is a compound, analogous to soaps, of soda with a peculiar substance, which has been named *choleic acid*. This acid is obtained in combination with oxide of lead, when bile, purified by means of alcohol from all matters insoluble in that menstruum, is mixed with acetate of lead.

Choleic acid is resolved, by the action of muriatic acid, into *ammonia, taurine,* and a new acid, *choloidic acid,* which contains no nitrogen.

When boiled with caustic potash, choleic acid is resolved into *carbonic acid, ammonia,* and another new acid, *cholic acid* (distinct from the cholic acid of Gmelin.)

Now it is clear that the true formula of choleic acid must include the analytical expression of these modes of decomposition; in other words, that it must enable us to show that the composition of the products derived from it is related in a clear and simple manner, to the composition of the acid itself. This is the only satisfactory test of a formula; and the analytical expression thus obtained loses nothing of its truth or value, if it should appear, as the researches of Berzelius seem to show, that choleic and choloidic acids are mixtures of different compounds; for the relative proportions of the elements cannot in any way be altered by this circumstance.

26. In order to develope the metamorphoses which choleic acid suffers under the influence of acids and alkalies, the following formula alone can be adopted as the empirical expression of the results of its analysis, Formula of choleic acid: $C^{76}N^{2}H^{66}O^{22}$. (29)

I repeat, that this formula may express the composition of one, or of two or more compounds; no matter of how many compounds the so-called choleic acid may be made up, the above formula represents the relative proportions of all their elements taken together.

If now we subtract from the elements of choleic acid, the products formed by the action of muriatic acid, namely, ammonia and taurine, we obtain the empirical formula of choloidic acid. Thus from the

$$\begin{array}{lll}
\text{Formula of choleic acid} & & C^{76}N^{2}H^{66}O^{22} \\
\quad\text{Substract—} & & \\
\left.\begin{array}{l}\text{1 at. taurine } C^{4}NH^{7}O^{10} \\ \text{1 eq. ammonia } NH^{3}\end{array}\right\} & = & \underline{C^{4}N^{2}H^{10}O^{10}} \\
\text{There remains the formula of choloidic acid} \;.\;.\;.\;.\;.\;. & = & C^{72}\;H^{56}O^{12} \;(30.)
\end{array}$$

27. Again, if from the formula of choleic acid we subtract the elements of urea and 2 atoms of water (=2 eq. carbonic acid and 2 eq. ammonia,) there will remain the formula and composition of cholic acid. Thus: from the

$$\begin{array}{lll}
\text{Formula of choleic acid} & = & C^{76}N^{2}H^{66}O^{22} \\
\quad\text{Substract—} & & \\
\left.\begin{array}{l}\text{2 eq. car. acid} = C^{2}\;O^{4} \\ \text{2 eq. ammonia} = N^{2}H^{6}\end{array}\right\} & = & \underline{C^{2}N^{2}\;H^{6}\;O^{4}} \\
\text{Remains the formula of cholic acid} & = & C^{74}\;H^{60}O^{18} \;(31.)
\end{array}$$

When we consider the very close coincidence between these formulæ and the actual results of analysis (see Appendix, 29, 30, 31,) it is scarcely possible to doubt that the formula above adopted for choleic acid expresses, as accurately as is to be expected in the analysis of such compounds, the relative proportion of its elements, no matter in how many different forms they may be united to produce that acid.

28. Let us now add the half of the numbers which represent the formula of choleic acid, to the elements of the urine of serpents—that is, to neutral urate of ammonia, as follows:

$$\begin{array}{lll}
\tfrac{1}{2}\text{ the formula of choleic acid} & = & C^{38}N^{1}H^{33}O^{11} \\
\quad\text{Add to this—} & & \\
\left.\begin{array}{l}\text{1 eq. uric acid} = C^{10}N^{4}H^{4}O^{6} \\ \text{1 eq. ammonia} = \quad NH^{3}\end{array}\right\} & = & \underline{C^{10}N^{5}H^{7}O^{6}} \\
\quad\text{The sum is} \;.\;.\;.\;.\;. & = & C^{48}N^{6}H^{40}O^{17}
\end{array}$$

29. But this last formula expresses the composition of blood, with the addition of 1 eq. oxygen, and 1 eq. water.

$$\begin{array}{lll}
\text{Formula of blood} \;.\;.\;.\;. & & C^{48}N^{6}H^{39}O^{15} \\
\left.\begin{array}{ll}\text{1 eq. water} & = HO \\ \text{1 eq. oxygen} & = \;\; O\end{array}\right\} & = & \underline{H^{1}\;O^{2}} \\
\quad\text{The sum is} \;.\;.\;.\;. & = & C^{48}N^{6}H^{40}O^{17}
\end{array}$$

30. If, moreover, we add to the elements of proteine those of 3 eq. water, we obtain, with the exception 1 eq. hydrogen, exactly the same formula.

$$\begin{array}{lll}
\text{Formula of proteine} \;.\;. & = & C^{48}N^{6}H^{36}O^{14} \\
\text{Add 3 eq. of water} \;.\;.\;. & = & \underline{H^{3}O^{3}} \\
\quad\text{The sum is} \;.\;.\;.\;. & & C^{48}N^{6}H^{39}O^{17}
\end{array}$$

differing only by 1 eq. of hydrogen from the formula above obtained by adding together choleic acid and urate of ammonia.

31. If, then, we consider choleic acid and urate of ammonia the products of the transformation of muscular fibre, since no other tissue in the body contains proteine (for albumen passes into tissues, without our being able to say, that in the vital process it is directly resolved into choleic acid, and urate of ammonia,) there exist in fibrine, with the addition of the elements of water, all the elements essential to this metamorphosis; and, except the sulphur and phosphorus, both of which are probably oxidized, no element is separated.

This form of metamorphosis is applicable to the vital transformations in the lower classes of amphibia, and perhaps in worms and insects. In the higher classes of animals the uric acid disappears in the urine, and is replaced by urea.

The disappearance of uric acid and the production of urea plainly stand in a very close relation to the amount of oxygen absorbed in respiration, and to the quantity of water consumed by different animals in a given time.

When uric acid is subjected to the action of oxygen, it is first resolved, as is well known, into alloxan and urea. (32.) A new supply of oxygen acting on the alloxan causes it to resolve itself either into oxalic acid and urea, into oxaluric and parabanic acids, (33,) or into carbonic acid and urea.

32. In the so-called mulberry calculi we find oxalate of lime, in other calculi urate of ammonia, and always in persons, in whom, from want of exercise and labour, or from other causes, the supply of oxygen has been diminished. Calculi containing uric acid or oxalic acid are never found in phthisical patients; and it is a common occurrence in France, among patients suffering from calculous complaints, that when they go to the country, where they take more exercise, the compounds of uric acid, which were deposited in the bladder during their residence in town, are succeeded by oxalates (mulberry calculus,) in consequence of the increased supply of oxygen. With a still greater supply of oxygen they would have yielded, in healthy subjects, only the last product of the oxidation of uric acid, namely, carbonic acid and urea.

An erroneous interpretation of the undeniable fact that all substances incapable of farther use in the organism are separated by the kidneys and expelled from the body in the urine, altered or unaltered, has led practical medical men to the idea, that the food, and especially nitrogenized food, may have a direct influence on the formation of urinary calculi. There are no reasons which support this opinion, while those opposed to it are innumerable. It is possible that there may be taken, in the food, a number of matters changed by the culinary art, which, as being no longer adapted to the formation of blood, are expelled in the urine, more or less altered by the respiratory process. But roasting and boiling alter in no way the composition of animal food. (34.)

Boiled and roasted flesh is converted at once into blood; while the uric acid and urea are derived from the metamorphosed tissues. The quantity of these products increases with the rapidity of transformation in a given time, but bears no proportion to the amount of food taken in the same period. In a starving man who is in any way compelled to undergo severe and continued exertion, more urea is secreted than in the most highly fed individual, if in a state of rest. In fevers and during rapid emaciation the urine contains more urea than in a state of health. (Prout.)

33. In the same way, therefore, as the hippuric acid, present in the urine of the horse when at rest, is converted into benzoate of ammonia and carbonic acid as soon as the animal is compelled to labour, so the uric acid disappears in the urine of man, when he receives, through the skin and lungs, a quantity of oxygen sufficient to oxidize the products of the transformation of the tissues. The use of wine and fat, which are only so far altered in the organism that they combine with oxygen, has a marked influence on the formation of uric acid. The urine, after fat food has been taken, is turbid, and deposits minute crystals of uric acid. (Prout.) The same thing is observed after the use of wines in which the alkali necessary to retain the uric acid in solution is wanting, but never from the use of Rhenish wines, which contain so much tartar.

In animals which drink much water, by means of which the sparingly soluble uric acid is kept dissolved, so that the inspired oxygen can act on it, no uric acid is found in the urine, but only urea. In birds, which seldom drink, uric acid predominates.

If to one atom of uric acid we add 6 atoms of oxygen and 4 atoms of water, it resolves itself into urea and carbonic acid:

$$\begin{array}{lll}
 & \text{1 atom uric acid} & C^{10}N^{4}H^{4}O^{6} \\
 & \left.\begin{array}{l}\text{4 atoms water} \\ \text{6 atoms oxygen}\end{array}\right\} & \underline{H^{4}O^{10}} \\
 & & C^{10}N^{4}H^{8}O^{16} \\
= & \left\{\begin{array}{l}\text{2 atoms urea} \;\;- \\ \text{6 atoms carbonic acid}\end{array}\right. & \begin{array}{l}C^{4}N^{4}H^{8}O^{4} \\ \underline{C^{6}\qquad O^{12}}\end{array} \\
 & & C^{10}N^{4}H^{8}O^{16}
\end{array}$$

34. The urine of the herbivora contains no uric acid, but ammonia, urea, and hippuric or benzoic acid. By the addition of 9 atoms of oxygen to the empirical formula of their blood multiplied by 5, we obtain the elements of 6 at. of hippuric acid, 9 at. of urea, 3 at. of choleic acid, 3 at. of water, and 3 at. of ammonia; or, if we suppose 45 atoms of oxygen to be added to the blood during its metamorphoses, then we obtain 6 at. of benzoic acid, 13½ at. of urea, 3 at of choleic acid, 15 at. of carbonic acid, and 12 at. of water.

$$5\,(C^{48}N^{6}H^{39}O^{15}) + O^{9} = C^{240}N^{30}H^{195}O^{84}$$

$$\begin{array}{llll}
= \left\{\begin{array}{l}\text{6 atoms hippuric acid,} \\ \text{9 atoms urea} \;.\;.\;. \\ \text{3 atoms choleic acid} \;. \\ \text{3 atoms ammonia} \;\;. \\ \text{3 atoms water} \;\;.\;.\end{array}\right. & \begin{array}{l}6\,(C^{18}N\,H^{8}\,O^{5}) \\ 9\,(C^{2}\,N^{2}H^{4}\,O^{2}) \\ 3\,(C^{38}N\,H^{38}O^{11}) \\ 3\,(\;\;N\,H^{3}\;\;) \\ 3\,(\;\;H^{3}\,O^{3}\;)\end{array} & \begin{array}{l}= \\ = \\ = \\ = \\ =\end{array} & \begin{array}{l}C^{108}N^{6}\,H^{48}O^{30} \\ C^{18}\,N^{18}H^{36}O^{18} \\ C^{114}N^{3}\,H^{99}O^{33} \\ N^{3}\,H^{9} \\ \underline{H^{3}\,O^{3}}\end{array} \\
\qquad\text{The sum is} \;.\;.\;.\;.\;.\;. & & & C^{240}N^{30}H^{195}O^{84}
\end{array}$$

Or—

$$5\,(C^{48}N^{6}H^{39}O^{15}) + O^{45} = C^{240}N^{30}H^{195}O^{120}$$

$$=\left\{\begin{array}{lll} \text{6 atoms benzoic acid,} & 6\,(C^{14}\;H^{5}O^{3}) & = C^{84}\quad H^{30}O^{18} \\ 27|^{2}\text{ atoms urea . . .} & 27\,(C\;NH^{2}O) & = C^{27}N^{27}H^{54}O^{27} \\ \text{3 atoms choleic acid} & 3\,(C^{38}NH^{33}O^{11}) & = C^{114}N^{3}H^{99}O^{33} \\ \text{15 atoms carbonic acid} & 15\,(C\quad O^{2}) & = C^{15}\quad O^{30} \\ \text{12 atoms water . .} & 12\,(\quad H\;O) & = \quad H^{12}O^{12} \\ \hline \text{The sum is . . . .} & & C^{240}N^{30}H^{195}O^{120} \end{array}\right.$$

35. Lastly, let us follow the metamorphosis of the tissues in the fœtal calf, considering the proteine furnished in the blood of the mother as the substance which undergoes or has undergone a transformation; it will appear that 2 at. of proteine without the addition of oxygen or any other foreign element, except 2 at. of water, contain the elements of 6 at. of allantoine and 1 at. of choloidic acid (meconium?)

$$\text{2 atoms proteine} = 2\,(C^{48}N^{6}H^{36}O^{14}) + \text{2 atoms water} = 2HO = C^{96}N^{12}H^{74}O^{30}$$

$$=\left\{\begin{array}{ll} \text{6 atoms allantoine, } 6\,(C^{4}N^{2}H^{3}O^{3}) & = C^{24}N^{12}H^{18}O^{18} \\ \text{1 atom choloidic acid} & = C^{72}\quad H^{56}O^{12} \\ \hline & C^{96}N^{12}H^{74}O^{30} \end{array}\right.$$

36. But the elements of the six atoms of allantoine in the last equation correspond exactly to the elements of 2 at. of uric acid, 2 at. of urea, and 2 at. of water.

$$\text{6 atoms of allantoine} = C^{24}N^{12}H^{18}O^{18} = \left\{\begin{array}{ll} \text{2 atoms uric acid} & C^{20}N^{8}H^{8}O^{12} \\ \text{2 atoms urea} & C^{4}N^{4}H^{8}O^{4} \\ \text{2 atoms water} & H^{2}O^{2} \\ \hline & C^{24}N^{12}H^{18}O^{18} \end{array}\right.$$

The relations of allantoine, which is found in the urine of the fœtal calf, to the nitrogenized constituents of the urine in animals which respire, are, as may be seen by comparing the above formulæ, such as cannot be overlooked or doubted. Allantoine contains the elements of uric acid and urea—that is, of the nitrogenized products of the transformation of the compounds of proteine.

37. Further, if to the formula of proteine, multiplied by 3, we add the elements of 4 at. of water, and if we deduct from the sum of all the elements half of the elements of choloidic acid, there remains a formula which expresses very nearly the composition of gelatine. From

$$\begin{array}{rl} 3\,(C^{48}N^{6}H^{36}O^{14}) + 4\,HO\;.\;.\;. & = C^{144}N^{18}H^{112}O^{46} \\ \text{Subtract } \tfrac{1}{2} \text{ atom choloidic acid} & = C^{36}\quad H^{25}O^{6} \\ \hline \text{There remain . . . .} & C^{108}N^{18}H^{84}O^{40}\,(35) \end{array}$$

38. Subtracting from this formula of gelatine the elements of 2 at. of proteine, there remain the elements of urea, uric acid, and water, or of 3 at. of allantoine and 3 at. of water. Thus—

$$\begin{array}{rl} \text{Formula of gelatine (Mulder)} & C^{108}N^{18}H^{84}O^{40} \\ \text{Subtract 2 atoms proteine .} & C^{96}N^{12}H^{72}O^{28} \\ \hline \text{There remain . . .} & C^{12}N^{6}H^{12}O^{12} \end{array}$$

$$=\left\{\begin{array}{ll} \text{1 atom uric acid} & C^{10}N^{4}H^{4}O^{6} \\ \text{1 atom urea .} & C^{2}N^{2}H^{4}O^{2} \\ \text{4 atoms water} & H^{4}O^{4} \\ \hline & C^{12}N^{6}H^{12}O^{12} \end{array}\right\} = \left\{\begin{array}{ll} \text{3 atoms allantoine} & C^{12}N^{6}H^{9}O^{9} \\ \text{3 atoms water .} & H^{3}O^{3} \\ \hline & C^{12}N^{6}H^{12}O^{12} \end{array}\right.$$

39. The numerical proportions calculated from the above formula differ from those actually obtained in the analyses of Mulder and Sherer in this, that the latter indicate somewhat less of nitrogen in gelatine; but if we assume the formula to be correct, it then appears, from the statement just given, that the elements of two atoms of proteine, *plus* the nitrogenized products of the transformation of a third atom of proteine (uric acid and urea) and water; or three atoms of proteine, *minus* the elements of a compound containing no nitrogen, which actually occurs as one of the products of the transformation of choleic acid, yield in both cases a formula closely approaching to the composition of gelatinous tissues. We must, however, attach to such formulæ, and to the considerations arising from them, no more importance than justly belongs to them. I would constantly remind the reader that their use is to serve as points of connexion, which may enable us to acquire more accurate views as to the production and decomposition of those compounds which form the animal tissues. They are the first attempts to discover the path which we must follow in order to attain the object of our researches; and this object, the goal we strive to reach, is, and must be, attainable.

The experience of all those who have occupied themselves with researches into natural phenomena leads to this general result, that these phenomena are caused or produced, by means far more simple than those previously supposed, or than we even now imagine; and it is precisely their simplicity

which should most powerfully excite our wonder and admiration.

Gelatinous tissue is formed from blood, from compounds of proteine. It may be produced by the addition, to the elements of proteine, of allantoine and water, or of water, urea, and uric acid; or by the separation from the elements of proteine of a compound containing no nitrogen. The solution of such problems becomes less difficult, when the problem to be solved, the question to be answered, is matured and clearly put. Every experimental decision of any such question in the negative forms the starting-point of a new question, the solution of which, when obtained, is the necessary consequence of our having put the first question.

40. In the foregoing sections, no other constituent of the bile, besides choleic acid, has been brought into the calculation; because it alone is known with certainty to contain nitrogen. Now, if it be admitted that its nitrogen is derived from the metamorphosed tissues, it is not improbable that the carbon, and other elements which it contains, are derived from the same source.

There cannot be the smallest doubt, that in the carnivora, the constituents of the urine and the bile are derived from the transformation of compounds of proteine; for, except fat, they consume no food but such as contains proteine, or has been formed from that substance. Their food is identical with their blood; and it is a matter of indifference which of the two we select as the starting-point of the chemical developement of the vital metamorphoses.

There can be no greater contradiction, with regard to the nutritive process, than to suppose that the nitrogen of the food can pass into the urine as urea, without having previously become part of an organized tissue; for albumen, the only constituent of blood, which, from its amount, ought to be taken into consideration, suffers not the slightest change in passing through the liver or kidneys; we find it in every part of the body with the same appearance and the same properties. These organs cannot be adapted for the alteration or decomposition of the substance from which all the other organs of the body are to be formed.

41. From the characters of chyle and lymph, it appears with certainty that the soluble parts of the food or of the chyme acquire the form of albumen. Hard-boiled white of egg, boiled or coagulated fibrine, which have again become soluble in the stomach, but have lost their coagulability by the action of air or heat, recover these properties by degrees. In the chyle, the acid reaction of the chyme has already passed into the weak alkaline reaction of the blood; and the chyle, when, after passing through the mesenteric glands, it has reached the thoracic duct, contains albumen coagulable by heat; and, when left to itself, deposits fibrine. All the compounds of proteine, absorbed during the passage of the chyme through the intestinal canal, take the form of albumen, which, as the results of incubation in the fowl's egg testify, contains the fundamental elements of all organized tissues, with the exception of iron, which is obtained from other sources.

Practical medicine has long ago answered the question, what becomes in man of the compounds of proteine taken in excess, what change is undergone by the superabundant nitrogenized food? The blood-vessels are distended with excess of blood, the other vessels with excess of their fluids, and if the too great supply of food be kept up, and the blood, or other fluids adapted for forming blood, be not applied to their natural purposes, if the soluble matters be not taken up by the proper organs, various gases are disengaged, as in processes of putrefaction, the excrements assume an altered quality in colour, smell, &c. Should the fluids in the absorbent and lymphatic vessels undergo a similar decomposition, this is immediately visible in the blood, and the nutritive process then assumes new forms.

42. No one of all these appearances should occur, if the liver and kidneys were capable of effecting the resolution of the superabundant compounds of proteine into urea, uric acid, and bile. All the observations which have been made in reference to the influence of nitrogenized food on the composition of the urine have failed entirely to demonstrate the existence of any direct influence of the kind; for the phenomena are susceptible of another and a far more simple interpretation, if, along with the food, we consider the mode of life and habits of the individuals who have been the subjects of investigation. Gravel and calculus occur in persons who use very little animal food. Concretions of uric acid have never yet been observed in carnivorous mammalia, living in the wild state,* and among nations which live entirely on flesh, deposits of uric acid concretions in the limbs or in the bladder are utterly unknown.

43. That which must be viewed as an undeniable truth in regard to the origin of the bile, or, more accurately speaking, of choleic acid in the carnivora, cannot hold in regard to all the constituents of the bile secreted by the liver in the herbivora, for with the enormous quantity of bile produced, for example, by the liver of an ox, it is absolutely impossible to suppose that all its carbon is derived from the metamorphosed tissues.

Assuming the 59 oz. of dry bile (from 37 lbs. of fresh bile secreted by an ox) to contain the same per centage of nitrogen as choleic acid, (3·86 per cent.,) this would amount to nearly 2¼ oz. of nitrogen; and if this nitrogen proceed from metamorphosed tissues, then, if all the carbon of these tissues passed into the bile, it would yield, at the utmost, a quantity of bile corresponding to 7·15 oz. of carbon. This is, however, far below the quantity which, according to observation, is secreted in this class of animals.

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* The occurrence of urate of ammonia in a concretion found in a dog, which was examined by Lassaigne, is to be doubted, unless Lassaigne extracted it himself from the bladder of the animal.

44. Other substances, besides compounds of proteine, must inevitably take part in the formation of bile in the organism of the herbivora; and these substances can only be the non-nitrogenized constituents of their food.

45. The sugar of bile of Gmelin (picromel or biline of Berzelius,) which Berzelius considers as the chief constituent of bile, while Demarçay assigns that place essentially to choleic acid, burns, when heated in the air, like resin, yields ammoniacal products, and when treated with acids, yields taurine and the products of the decomposition of *choleic acid;* when acted on by alkalies, it yields ammonia and *cholic acid.* At all events, the sugar of bile contains nitrogen, and much less oxygen than starch or sugar, but more oxygen than the oily acids. When, in the metamorphosis of sugar of bile or choleic acid by alkalies, we cause the separation of nitrogen, we obtain a crystallized acid, very similar to the oily acids (cholic acid,) and capable of forming with bases salts, which have the general characters of soaps. Nay, we may even consider the chief constituents of the bile, sugar of bile and choleic acid, as compounds of oily acids with organic oxides, like the fat oils, and only differing from these in containing no oxide of glycerule. Choleic acid, for example, may be viewed as a compound of choloidic acid with allantoine and water:

Choloid. acid. Allant. Water. Choleic acid.

$$C^{72}H^{56}O^{12}+C^4N^2H^3O^3+H^7O^7=C^{76}N^2H^{66}O^{22}$$

Or as a compound of cholic acid, urea, and water:

Cholic acid. Urea. Water. Choleic acid.

$$C^{74}H^{60}O^{18}+C^2N^2H^4O^2+H^2O^2=C^{76}N^2H^{66}O^{22}$$

46. If, in point of fact, as can hardly be doubted, the elements of such substances as starch, sugar, &c., take part in the production of bile in the organism of the herbivora, there is nothing opposed to such a view in the composition of the chief constituents of bile, as far as our knowledge at present extends.

If starch be the chief agent in this process, it can happen in no other way but this—that, as when it passes into fat, a certain quantity of oxygen is separated from the elements of the starch, which, for the same amount of carbon, (for 72 atoms,) contains five times as much oxygen as choloidic acid.

Without the separation of oxygen from the elements of starch, it is impossible to conceive its conversion into bile; and this separation being admitted, its conversion into a compound intermediate in composition between starch and fat offers no difficulty.

47. Not to render these considerations a mere idle play with formulæ, and not to lose sight of our chief object, we observe, therefore, that the consideration of the quantitative proportion of the bile secreted in the herbivora leads to the following conclusions:—

The chief constituents of the bile of the herbivora contain nitrogen, and this nitrogen is derived from compounds of proteine.

The bile of this class of animals contains more carbon than corresponds to the quantity of nitrogenized food taken, or to the portion of tissue that has undergone metamorphosis in the vital process.

A part of this carbon must, therefore, be derived from the non-nitrogenized parts of the food (starch, sugar, &c.;) and in order to be converted into a nitrogenized constituent of bile, a part of the elements of these bodies must necessarily have combined with a nitrogenized compound derived from a compound of proteine.

In reference to this conclusion, it is quite indifferent whether that compound of proteine be derived from the food or from the tissues of the body.

48. It has very lately been stated by A. Ure, that benzoic acid, when administered internally, appears in the urine in the form of hippuric acid.

Should this observation be confirmed,* it will acquire great physiological significance, since it would plainly prove that the act of transformation of the tissues in the animal body, under the influence of certain matters taken in the food, assumes a new form with respect to the products which are its result; for hippuric acid contains the elements of lactate of urea, with the addition of those of benzoic acid:

$$\left.\begin{array}{lll} \text{1 at. urea} & . \quad . & C^2N^2H^4O^2 \\ \text{1 at. lactic acid} & . \quad . & C^6\ H^4O^4 \\ \text{2 at. benzoic acid} & . & C^{28}\ H^{10}O^6 \end{array}\right\}$$

$$\overline{C^{36}N^2H^{18}O^{12}}$$

$$=\left\{\begin{array}{l}\text{2 at. chrystallized hippuric} \\ \text{acid} = 2\,(C^{18}NH^9O^6)\end{array}\right.$$

49. If we consider the act of transformation of the tissues in the herbivora as we have done in the carnivora, then the blood of the former must yield, as the last products of the metamorphosis, from all the organs taken together, choleic acid, uric acid, and ammonia (see p. 44;) and if we ascribe to the uric acid an action similar to that of the benzoic acid in Ure's observation—such, namely, that the further transformation, owing to the presence of this acid, assumes another form, the elements of the uric acid being incorporated in the final products—it will appear, for example, that 2 at. of proteine, with the addition of the elements of 3 at. of uric acid and 2 at. of oxygen, might give rise to the production of hippuric acid and urea.

$$\begin{array}{lrl} \text{2 at. proteine,} & 2\,(C^{48}N^6H^{36}O^{14}) & = C^{96}N^{12}H^{72}O^{28} \\ \text{3 at. uric acid,} & 3\,(C^{10}N^4H^4O^6) & = C^{30}N^{12}H^{12}O^{18} \\ \text{2 at. oxygen} & & = O^2 \\ \hline \text{The sum is} & . \quad . \quad . & = C^{126}N^{24}H^{84}O^{48} = \end{array}$$

$$=\left\{\begin{array}{lrl} \text{6 at. hippuric acid,} & 6\,(C^{18}N\ H^8O^5) & = C^{108}N^6\ H^{48}O^{30} \\ \text{9 at. urea} \quad . \quad . \quad . & 9\,(C^2N^2H^4O^2) & = C^{18}N^{18}H^{36}O^{18} \end{array}\right.$$

$$\begin{array}{lrl} \hline \text{The sum is} & . \quad . \quad . \quad . & = C^{126}N^{24}H^{84}O^{48} \end{array}$$

50. Finally, if we bear in mind, that, in the herbivora, the non-nitrogenized constituents of their food (starch, &c.) must, as we have shown, play an essential part in the formation of the bile; that to their elements must of necessity be added those of a nitrogenized compound, in order to produce the nitrogenized constituents of the bile, the most striking result of the combinations thus suggested is this, that the elements of starch added to those of hippuric acid are equal to the elements of choleic acid, *plus*, a certain quantity of carbonic acid:

$$\begin{array}{lrl} \text{2 at. hippuric acid,} & 2\,(C^{18}NH^8O^5) & = C^{36}N^2H^{16}O^{10} \\ \text{5 at. starch} \quad . \quad . & 5\,(C^{12}\ H^{10}O^{10}) & = C^{60}\ H^{50}O^{50} \\ \text{2 at. oxygen} \quad . \quad . & & = O^2 \\ \hline \text{The sum is} & . \quad . \quad . \quad . \quad . \quad . & = C^{96}N^2H^{66}O^{62} \end{array}$$

$$=\left\{\begin{array}{lrl} \text{2 at. choleic acid} & 2\,(C^{38}NH^{33}O^{11}) & = C^{76}N^2H^{66}O^{22} \\ \text{20 at. carbonic acid} & 20\,(C\ O^2) & = C^{20}\ O^{40} \end{array}\right.$$

$$\begin{array}{lrl} \hline \text{The sum is} & . \quad . \quad . \quad . \quad . \quad . \quad . & = C^{96}N^2H^{66}O^{62} \end{array}$$

51. Now since hippuric acid may be derived, along with urea, from the compounds of proteine, when to the elements of the latter are added those of uric acid (see p. 49;) since, further, uric acid, choleic acid, and ammonia contain the elements of proteine in a proportion almost identical with that of proteine itself (see p. 44;) it is obvious that, if from 5 at. of proteine, with the addition of oxygen and of the elements of water, there be removed the elements of choleic acid and ammonia, the remainder will represent the elements of hippuric acid and of urea; and that if, when this separation occurs, and during the further transformation, the elements of starch be present and enter into the new products, we shall obtain an additional quantity of choleic acid, as well as a certain amount of carbonic acid gas.

That is to say—that if the elements of proteine and starch, oxygen and water being also present, undergo transformation together and mutually affect each other, we obtain, as the product of this metamorphosis, urea, choleic acid, ammonia, and carbonic acid, and besides these, no other product whatever.

The elements of

$$\left.\begin{array}{r} \text{5 at. proteine} \\ \text{15 at. starch} \\ \text{12 at. water} \\ \text{5 at. oxygen} \end{array}\right\} = \left\{\begin{array}{l} \text{9 at. choleic acid} \\ \text{9 at. urea} \\ \text{3 at. ammonia} \\ \text{60 at. carbonic acid} \end{array}\right.$$

In detail

$$\begin{array}{lrl} \text{5 at. proteine,} & 5\,(C^{48}N^6H^{36}O^{14}) & = C^{240}N^{30}H^{180}O^{70} \\ \text{15 at. starch,} & 15\,(C^{12}\ H^{10}O^{10}) & = C^{180}\ H^{150}O^{150} \\ \text{12 at. water,} & 12\,(HO) & = H^{12}O^{12} \\ \text{5 at. oxygen} & & = O^5 \\ \hline \text{The sum is} & . \quad . \quad . \quad . & = C^{420}N^{30}H^{342}O^{237} \end{array}$$

and—

$$\begin{array}{lrl} \text{9 at. choleic acid,} & 9\,(C^{38}NH^{33}O^{11}) & = C^{342}N^9H^{297}O^{99} \\ \text{9 at. urea,} \quad . \quad . \quad . & 9\,(C^2N^2H^4O^2) & = C^{18}N^{18}H^{36}O^{18} \\ \text{3 at. ammonia,} \quad . & 3\,(N\ H^3) & = N^3H^9 \\ \text{60 at. carbonic acid,} & 60\,(C\ O^2) & = C^{60}\ O^{120} \\ \hline \text{The sum is} & . \quad . \quad . \quad . \quad . \quad . \quad . & = C^{420}N^{30}H^{342}O^{237} \end{array}$$

The transformation of the compounds of proteine present in the body is effected by means of the oxygen conveyed by the arterial blood, and if the elements of starch, rendered soluble in the stomach, and thus carried to every part, enter into the newly formed compounds, we have the chief constituents of the animal secretions and excretions; carbonic acid, the excretion of the lungs, urea and carbonate of ammonia, excreted by the kidneys, and choleic acid, secreted by the liver.

Nothing, therefore, in the chemical composition of those matters which may be supposed to take a share in these metamorphoses, is opposed to the supposition that a part of the carbon of the non azotized food enters into the composition of the bile.

52. Fat, in the animal body, disappears when the supply of oxygen is abundant.

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* The analysis of the crystals deposited from the urine on the addition of muriatic acid has not been performed. Besides, the statement of A. Ure, that hippuric acid, dissolved in nitric acid, is reddened by ammonia, is erroneous, and shows that the crystals he obtained must have contained uric acid.

When that supply is deficient, choleic acid may be converted into hippuric acid, lithofellic acid, (37) and water. Lithofellic acid is known to be the chief constituent of the bezoar stones, which occur in certain herbivorous animals:

$$\left.\begin{array}{ll} \text{2 at. choleic acid} & C^{76}N^{2}H^{66}O^{22} \\ \text{10 at. oxygen . .} & O^{10} \end{array}\right\} = \left\{\begin{array}{ll} \text{2 at. hip. acid} & C^{36}N^{2}H^{16}O^{10} \\ \text{1 at. lith. acid} & C^{40}\;H^{36}O^{8} \\ \text{14 at. water . .} & H^{14}O^{14} \end{array}\right.$$

$$\overline{C^{76}N^{2}H^{66}O^{32}} \qquad\qquad \overline{C^{76}N^{2}H^{66}O^{32}}$$

53. For the production of bile in the animal body a certain quantity of soda is, in all circumstances, necessary; without the presence of a compound of sodium no bile can be formed. In the absence of soda, the metamorposis of the tissues composed of proteine can yield only fat and urea. If we suppose fat to be composed according to the empirical formula $C^{11}H^{10}O$, then, by the addition of oxygen and the elements of water, to the elements of proteine, we have the elements of fat, urea, and carbonic acid

$$2\,(\overset{\text{Proteine.}}{C^{48}N^{6}H^{36}O^{14}}) + \overset{\text{Water.}}{12\,HO} + \overset{\text{Oxygen.}}{14\,O} = C^{96}N^{12}H^{84}O^{54} =$$

$$= \left\{\begin{array}{ll} \text{6 at. urea . . .} & = C^{12}N^{12}H^{24}O^{12} \\ \text{Fat . . . . . .} & = C^{66}\;H^{60}O^{6} \\ \text{18 at. carbonic acid} & = C^{18}\;O^{36} \end{array}\right.$$

$$\overline{C^{96}N^{12}H^{84}O^{54}}$$

The composition of all fats lies between the empirical formulæ $C^{11}H^{10}O$ and $C^{12}H^{10}O$. If we adopt the latter, then the elements of 2 at. proteine, with the addition of 2 at. oxygen and 12 at. water, will yield 6 at. urea, fat ($C^{72}H^{60}O^{6}$), and 12 at. carbonic acid.

It is worthy of observation, in reference to the production of fat, that the absence of common salt (a compound of sodium which furnishes soda to the animal organism) is favorable to the formation of fat; that the fattening of an animal is rendered impossible, when we add to its food an excess of salt, although short of the quantity required to produce a purgative effect.

54. As a kind of general view of the metamorphoses of the nitrogenized animal secretions, attention may here be very properly directed to the fact, that the nitrogenized products of the transformation of the bile are identical in ultimate composition with the constituents of the urine, if to the latter be added a certain proportion of the elements of water.

$$\left.\begin{array}{ll} \text{1 at. uric acid} & C^{10}N^{4}H^{4}O^{6} \\ \text{1 at. urea . . .} & C^{2}N^{2}H^{4}O^{2} \\ \text{22 at. water . .} & H^{22}O^{22} \end{array}\right\} =$$

$$\overline{C^{12}N^{6}H^{30}O^{30}}$$

$$= \left\{\begin{array}{ll} \text{3 at. taurine} & C^{12}N^{3}H^{21}O^{30} \\ \text{3 at. ammonia} & N^{3}H^{9} \end{array}\right.$$

$$\overline{C^{12}N^{6}H^{30}O^{30}}$$

$$\left.\begin{array}{ll} \text{1 at. allantoine} & C^{4}N^{2}H^{3}O^{3} \\ \text{1 at. water . .} & H^{7}O^{7} \end{array}\right\} =$$

$$\overline{C^{4}N^{2}H^{10}O^{10}}$$

$$= \left\{\begin{array}{ll} \text{1 at. taurine} & C^{4}N\,H^{7}O^{10} \\ \text{1 at. ammonia} & N\,H^{3} \end{array}\right.$$

$$\overline{C^{4}N^{2}H^{10}O^{10}}$$

55. In reference to the metamorphoses of uric acid of the products of the transformation of the bile, it is not less significant, and worthy of remark, that the addition of oxygen and the elements of water to the elements of uric acid may yield either taurine and urea, or taurine, carbonic acid, and ammonia.

$$\left.\begin{array}{ll} \text{1 at. uric acid} & C^{10}N^{4}H^{4}O^{6} \\ \text{14 at. water . .} & H^{14}O^{14} \\ \text{2 at. oxygen} & O^{2} \end{array}\right\} = \left\{\begin{array}{ll} \text{2 at. taurine} & C^{8}N^{2}H^{14}O^{20} \\ \text{1 at. urea .} & C^{2}N^{2}H^{4}O^{2} \end{array}\right.$$

$$\overline{C^{10}N^{4}H^{18}O^{22}} \qquad\qquad \overline{C^{10}N^{4}H^{18}O^{22}}$$

$$\left.\begin{array}{l} C^{10}N^{4}H^{18}O^{22} \\ \\ \text{Add 2 at. water } H^{2}\;O^{2} \end{array}\right\} = \left\{\begin{array}{ll} \text{2 at. taurine} & C^{8}N^{2}H^{14}O^{20} \\ \text{2 at. carbonic acid} & C^{2}\;O^{4} \\ \text{2 at. ammonia} & N^{2}H^{6} \end{array}\right.$$

$$\overline{C^{10}N^{4}H^{20}O^{24}} \qquad\qquad \overline{C^{10}N^{4}H^{20}O^{24}}$$

56. Alloxan, *plus* a certain amount of water, is identical in the proportion of elements with taurine; and finally, taurine contains the elements of super-oxalate of ammonia.

$$\left.\begin{array}{ll} \text{1 at. alloxan*} & C^{8}N^{2}H^{4}O^{10} \\ \text{10 at. water} & H^{10}O^{10} \end{array}\right\} = (2\,\overset{\text{Taurine.}}{C^{4}NH^{7}O^{10}})$$

$$\text{1 at. taurine } C^{4}NH^{7}O^{10} = \left\{\begin{array}{ll} \text{2 at. oxalic acid} & C^{4}\;O^{6} \\ \text{1 at. ammonia} & NH^{3} \\ \text{4 at. water . .} & H^{4}O^{4} \end{array}\right.$$

$$\overline{C^{4}NH^{7}O^{10}}$$

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* It would be most interesting to investigate the action of alloxan on the human body. Two or three drachms, in crystals, had no injurious action on rabbits to which it was given. In man, a large dose appeared to act only on the kidneys. In certain diseases of the liver, alloxan would very probably be found a most powerful remedy. —J. L.

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57. The comparison of the amount of carbon in the bile secreted by an herbivorous animal, with the quantity of carbon of its tissues, or of the nitrogenized constituents of its food, which in consequence of the constant transformations may pass into bile, indicates, as we have just seen, a great difference.

The carbon of the bile secreted amounts, at least, to more than five times the quantity of that which could reach the liver in consequence of the change of matter in the body, either from the metamorphosed tissues or from the nitrogenized constituents of the food; and we may regard as well founded the supposition that the non-azotized constituents of the food take a decided share in the production of bile in the herbivora; for neither experience nor observation contradicts this opinion.

58. We have given, in the foregoing paragraphs, the analytical proof, that the nitrogenized products of the transformation of bile, namely, taurine and ammonia, may be formed from all the constituents of the urine, with the exception of urea—that is, from hippuric acid, uric acid, allantoine; and when we bear in mind that, by the mere separation of oxygen and the elements of water, choloidic acid may be formed from starch;—

$$\begin{array}{ll} \text{From 6 at. starch} = (C^{12}H^{10}O^{10}) = & C^{72}H^{60}O^{60} \\ \left.\begin{array}{r} \text{Subtract 44 at. oxygen} \\ \text{4 at. water} \end{array}\right\} = & H^{4}O^{48} \\ \text{Remains choloidic acid . . .} & = \overline{C^{72}H^{56}O^{12}}; \end{array}$$

that, finally, choloidic acid, ammonia, and taurine, if added together, contain the elements of choleic acid;—

$$\begin{array}{ll} \text{1 at. choloidic acid} & = C^{72}\;H^{56}O^{12} \\ \text{1 at. taurine . . .} & = C^{4}N\,H^{7}\,O^{10} \\ \text{1 at. ammonia . .} & = \;N\,H^{3} \\ \hline \text{1 at. choleic acid} & = \overline{C^{76}N^{2}H^{66}O^{22}};\text{—} \end{array}$$

if all this be considered, every doubt as to the possibility of these changes is removed.

59. Chemical analysis and the study of the living animal body mutually support each other; and both lead to the conclusion that a certain portion of the carbon of the non-azotized constituents of food (of starch, &c., the elements of respiration) is secreted by the liver in the form of bile; and further, that the nitrogenized products of the transformation of tissues in the herbivora do not, as in the carnivora, reach the kidneys immediately or directly, but that, before their expulsion from the body in the form of urine, they take a share in certain other processes, especially in the formation of the bile.

They are conveyed to the liver with the non-azotized constituents of the food; they are returned to the circulation in the form of bile, and are not expelled by the kidneys till they have thus served for the production of the most important of the substances employed in respiration.

60. When the urine is left to itself, the urea which it contains is converted into carbonate of ammonia; the elements of urea are in such proportion, that by the addition of the elements of water, all its carbon is converted into carbonic acid, and all its nitrogen into ammonia.

$$\left.\begin{array}{ll} \text{1 at. urea} & C^{2}N^{2}H^{4}O^{2} \\ \text{2 at. water} & H^{2}O^{2} \end{array}\right\} =$$

$$\overline{C^{2}N^{2}H^{6}O^{4}}$$

$$= \left\{\begin{array}{ll} \text{2 at. carbonic acid} & C^{2}\;O^{4} \\ \text{2 at. ammonia . . . .} & N^{2}H^{6} \end{array}\right.$$

$$\overline{C^{2}N^{2}H^{6}O^{4}}$$

61. Were we able directly to produce taurine and ammonia out of uric acid or allantoine, this might perhaps be considered as an additional proof of the share which has been ascribed to these compounds in the production of bile; it cannot, however, be viewed as any objection to the views above developed on the subject, that, with the means we possess, we have not yet succeeded in effecting these transformations out of the body. Such an objection loses all its force, when we consider that we cannot admit, as proved, the pre-existence of taurine and ammonia in the bile; nay, that it is not even probable that these compounds, which are only known to us as products of the decomposition of the bile, exist ready formed, as ingredients of that fluid.

By the action of muriatic acid on bile, we, in a manner, force its elements to unite in such forms as are no longer capable of change under the influence of the same reagent; and when, instead of the acid, we use potash, we obtain the same elements, although arranged in another, and quite a different manner. If taurine were present, ready formed, in bile, we should obtain the same products by the action of acids and of alkalies. This, however, is contrary to experience.

Thus, even if we could convert allantoine, or uric acid and urea, into taurine and ammonia, out of the body, we should acquire no additional insight into the true theory of the formation of bile, just because the pre-existence of ammonia and taurine in the bile must be doubted, and because we have no reason to believe that urea or allantoine, as such, are employed by the organism in the production of bile. We can prove that their elements serve this purpose, but we are utterly ignorant how these elements enter into these combinations, or what is the chemical character of the nitrogenized compound which unites with the elements of starch to form bile, or rather choleic acid.

62. Choleic acid may be formed from the elements of starch with those of uric acid and urea, or of allantoine, or of uric acid, or of alloxan, or of oxalic acid and ammonia, or of hippuric acid. The possibility of its being produced from so great a variety of nitrogenized compounds is sufficient to show that all the nitrogenized products of the metamorphosis of the tissues may be employed in the formation of bile,

while we cannot tell in what precise way they are so employed.

By the action of caustic alkalies allantoine may be resolved into oxalic acid and ammonia; the same products are obtained when oxamide is acted on by the same reagents. Yet we cannot, from the similarity of the products, conclude that these two compounds have a similar constitution. In like manner the nature of the products formed by the action of acids on choleic acid does not entitle us to draw any conclusion as to the form in which its elements are united together.

63. If the problem to be solved by organic chemistry be this, namely, to explain the changes which the food undergoes in the animal body; then it is the business of this science to ascertain what elements must be added, what elements must be separated, in order to effect, or, in general, to render possible, the conversion of a given compound into a second or a third; but we cannot expect from it the synthetic proof of the accuracy of the views entertained, because every thing in the organism goes on under the influence of the vital force, an immaterial agency, which the chemist cannot employ at will.

The study of the phenomena which accompany the metamorphoses of the food in the organism, the discovery of the share which the atmosphere or the elements of water take in these changes, lead at once to the conditions which must be united in order to the production of a secretion or of an organized part.

64. The presence of free muriatic acid in the stomach, and that of soda in the blood, prove beyond all doubt the necessity of common salt for the organic processes; but the quantities of soda required by animals of different classes, to support the vital processes, are singularly unequal.

If we suppose that a given amount of blood, considered as a compound of soda, passes, in the body of a carnivorous animal, in consequence of the change of matter, into a new compound of soda, namely, the bile, we must assume, that in the normal condition of health, the proportion of soda in the blood is amply sufficient to form bile with the products of transformation. The soda which has been used in the vital processes, and any excess of soda must be expelled in the form of a salt, after being separated from the blood by the kidneys.

Now, if it be true, that, in the body of an herbivorous animal, a much larger quantity of bile is produced than corresponds to the amount of blood formed or transformed in the vital processes; if the greater part of the bile, in this case, proceeds from the non-azotised constituents of the food, then the soda of the blood which has been formed into organized tissue (assimilated or metamorphosed) cannot possibly suffice for the supply of the daily secretion of bile. The soda, therefore, of the bile of the herbivora must be supplied directly in the food; their organism must possess the power of applying directly to the formation of bile all the compounds of soda present in the food, and decomposable by the organic process. All the soda of the animal body obviously proceeds from the food, but the food of the carnivora contains, at most, only the amount of soda necessary to the formation of blood; and in most cases, among animals of this class, we may assume that only as much soda as corresponds to the proportion employed to form the blood is expelled in the urine.

When the carnivora obtain in their food as much soda as suffices for the production of their blood, an equal amount is excreted in the urine; when the food contains less, a part of that which would otherwise be excreted is retained by the organism.

All these statements are most unequivocally confirmed by the composition of the urine in these different classes of animals.

65. As the ultimate product of the changes of all compounds of soda in the animal body, we find in the urine the soda in the form of a salt, and the nitrogen in that of ammonia or urea.

The soda in the urine of the carnivora is found in combination with sulphuric and phosphoric acids; and along with the sulphate and phosphate of soda we never fail to find a certain quantity of a salt of ammonia, either muriate or phosphate of ammonia. There can be no more decisive evidence in favour of the opinion, that the soda of their bile or of the metamorphosed constituents of their blood is very far from sufficing to neutralize the acids which are separated, than the presence of ammonia in their urine. This urine, moreover, has an acid reaction.

In contradistinction to this, we find, in the urine of the herbivora, soda in predominating quantity; and that not combined with sulphuric or phosphoric acids, but with carbonic, benzoic, or hippuric acids.

65. These well established facts demonstrate that the herbivora consume a far larger quantity of soda than is required merely for the supply of the daily consumption of blood. In their food are united all the conditions for the production of a second compound of soda, destined for the support of the respiratory process; and it can only be a very limited knowledge of the vast wisdom displayed in the arrangements of organized nature which can look on the presence of so much soda in the food and in the urine of the herbivora as accidental.

It cannot be accidental, that the life, the developement of a plant is dependent on the presence of the alkalies which it extracts from the soil. This plant serves as food to an extensive class of animals, and in these animals the vital process is again most closely connected with the presence of these alkalies. We find the alkalies in the bile, and their presence in the animal body is the indispensable condition for the production of the first food of the young animal; fc

without an abundant supply of potash, the production of milk becomes impossible.

67. All observation leads, as appears from the preceding exposition, to the opinion, that certain non-azotized constituents of the food of the herbivora (starch, sugar, gum, &c.,) acquire the form of a compound of soda, which, in their bodies, serves for the same purpose as that which we know certainly to be served by the bile (the most highly carbonized product of the transformation of their tissues) in the bodies of the carnivora. These substances are employed to support certain vital actions, and are finally consumed in the generation of animal heat, and in furnishing means of resistance to the action of the atmosphere. In the carnivora, the rapid transformation of their tissues is a condition of their existence, because it is only as the result of the change of matter in the body that those substances can be formed, which are destined to enter into combination with the oxygen of the air; and in this sense we may say that the non-azotized constituents of the food of the herbivora impede the change of matter, or retard it, and render unnecessary, at all events, so rapid a process as occurs in the carnivora.

68. The quantity of azotized matter, proportionally so small, which the herbivora require to support their vital functions, is closely connected with the power possessed by the non-azotized parts of their food to act as means of supporting the respiratory process; and this consideration seems to render it not improbable, that the necessity for more complex organs of digestion in the herbivora is rather owing to the difficulty of rendering soluble and available for the vital processes certain non-azotized compounds (gum? amylaceous fibre?) than to any thing in the change or transformation of vegetable fibrine, albumen and caseine into blood; since, for this latter purpose, the less complex digestive apparatus of the carnivora is amply sufficient.

69. If, in man, when fed on a mixed diet, starch perform a similar part to that which it plays in the body of the herbivora; if it be assumed that the elements of starch are equally necessary to the formation of the bile in man as in these animals; then it follows that a part of the azotized products of the transformation of the tissues in the human body, before they are expelled through the bladder, returns into the circulation from the liver in the shape of bile, and is separated by the kidneys from the blood, as the ultimate product of the respiratory process.

70. When there is a deficiency of non-azotized matter in the food of man, this form of the production of bile is rendered impossible. In that case, the secretions must possess a different composition; and the appearance of uric acid in the urine, the deposition of uric acid in the joints and in the bladder, as well as the influence which an excess of animal food (which must be considered equivalent to a deficiency of starch, &c.,) exercises on the separation of uric acid in certain individuals, may be explained on this principle. If starch, sugar, &c., be deficient, then a part of the azotized compounds formed during the change of matter will either remain in the situation where they have been formed, in which case they will be sent from the liver in the circulation, and therefore will not undergo the final changes dependent on the action of oxygen; or they will be separated by the kidneys in some form different from the normal one.

71. In the preceding paragraphs I have endeavoured to prove that the non-azotized constituents of food exercise a most decided influence on the nature and quality of the animal secretions. Whether this occur directly; whether, that is to say, their elements take an immediate share in the act of transformation of tissues; or whether their share in that process be an indirect one, is a question probably capable of being resolved by careful and cautious experiment and observation. It is possible, that the non-azotized constituents of food, after undergoing some change, are carried from the intestinal canal directly to the liver, and that they are converted into bile in this organ, where they meet with the products of the metamorphosed tissues, and subsequently complete their course through the circulation.

This opinion appears more probable, when we reflect that as yet no trace of starch or sugar has been detected in arterial blood, not even in animals which had been fed exclusively with these substances. We cannot ascribe to these substances, since they are wanting in arterial blood, any share in the nutritive process; and the occurrence of sugar in the urine of those affected with diabetes mellitus (which sugar, according to the best observations, is derived from the food) coupled with its total absence in the blood of the same patients, obviously proves that starch and sugar are not, as such, taken into the circulation.

72. The writings of physiologists contain many proofs of the presence of certain constituents of the bile in the blood of man in a state of health, although their quantity can hardly be determined. Indeed, if we suppose 8¼ lbs. (58,000 grs.) of blood to pass through the liver every minute, and if from this quantity of blood 2 drops of bile (3 grains to the drop) are secreted, this would amount to $\frac{1}{9600}$th part of the weight of the blood, a proportion far too small to be quantitatively ascertained by analysis.

73. The greater part of the bile in the body of the herbivora, and in that of man fed on mixed food, appears from the preceding considerations to be derived from the elements of the non-azotized food. But its formation is impossible without the addition of an azotized body, for the bile is a compound of nitrogen. All varieties of bile yet examined,

yield, when subjected to dry distillation, ammonia and other nitrogenized products. Taurine and ammonia may easily be extracted from ox bile; and the only reason why we cannot positively prove that the same products may be obtained from the bile of other animals is this, that it is not easy to procure, in the case of many of these animals, a sufficient quantity of bile for the experiment,

Now, whether the nitrogenized compound which unites with the elements of starch to form bile be derived from the food or from the substance of the metamorphosed tissues, the conclusion that its presence is an essential condition for the secretion of bile cannot be considered doubtful.

Since the herbivora obtain in their food only such nitrogenized compounds as are identical in composition with the constituents of their blood, it is at all events clear, that the nitrogenized compound which enters into the composition of bile is derived from a compound of proteine. It is either formed in consequence of a change which the compounds of proteine in the food have undergone, or it is produced from the blood or from the substance of the tissues by the act of their metamorphosis.

74. If the conclusion be accurate, that nitrogenized compounds, whether derived from the blood or from the food, take a decided share in the formation of the secretions, and particularly of the bile, then it is plain that the organism must possess the power of causing foreign matters, which are neither parts nor constituents of the organs in which vital activity resides, to serve for certain vital processes. All nitrogenized substances capable of being rendered soluble, without exception, when introduced into the organs of circulation or of digestion, must, if their composition be adapted for such purposes, be employed by the organism in the same manner as the nitrogenized products which are formed in the act of metamorphosis of tissues.

We are acquainted with a multitude of substances, which exercise a most marked influence on the act of transformation as well as on the nutritive process, while their elements take no share in the resulting changes. These are uniformly substances the particles of which are in a certain state of motion or decomposition, which state is communicated to all such parts of the organism as are capable of undergoing a similar transformation.

75. Medicinal and poisonous substances form a second and most extensive class of compounds, the elements of which are capable of taking a direct or an indirect share in the processes of secretion and of transformation. These may be subdivided into three great orders; the first (which includes the metallic poisons) consists of substances which enter into chemical combination with certain parts or constituents of the body, while the vital force is insufficient to destroy the compounds thus formed. The second division, consisting of the essential oils, camphor, empyreumatic substances, and antiseptics, &c., possesses the property of impeding or retarding those kinds of transformation to which certain very complex organic molecules are liable; transformations which, when they take place out of the body, are usually designated by the names of fermentation and putrefaction.

The third division of medicinal substances is composed of bodies, the elements of which take a direct share in the changes going on in the animal body. When introduced into the system, they augment the energy of the vital activity of one or more organs; they excite morbid phenomena in the healthy body. All of them produce a marked effect in a comparatively small dose, and many are poisonous when administered in larger quantity. None of the substances in this class can be said to take a decided share in the nutritive process, or to be employed by the organism in the production of blood; partly, because their composition is different from that of blood, and partly, because the proportion in which they must be given, to exert their influence, is as nothing, compared with the mass of the blood.

These substances, when taken into the circulation, alter, as is commonly said, the quality of the blood, and in order that they may pass from the stomach into the circulation with their entire efficacy, we must assume that their composition is not affected by the organic influence of the stomach. If insoluble when given, they are rendered soluble in that organ, but they are not decomposed; otherwise, they would be incapable of exerting any influence on the blood.

76. The blood, in its normal state, possesses two qualities closely related to each other, although we may conceive one of them to be quite independent of the other.

The blood contains, in the form of the globules, the carriers, as it were, of the oxygen which serves for the production of certain tissues, as well as for the generation of animal heat. The globules of the blood, by means of the property they possess of giving off the oxygen they have taken up in the lungs, without losing their peculiar character, determine generally the change of matter in the body.

The second quality of the blood, namely the property which it possesses of becoming part of an organized tissue, and its consequent adaptation to promote the formation and the growth of organs, as well as to the reproduction or supply of waste in the tissues, is owing, chiefly, to the presence of dissolved fibrine and albumen. These two chief constituents, which serve for nutrition and reproduction of matter, in passing through the lungs are saturated with oxygen, or, at all events, absorb so much from the atmosphere as entirely to lose the power of extracting oxygen from the other substances present in the blood.

77. We know for certain that the globules of the venous blood, when they come in contact with air in the lungs, change their colour, and that this change of colour is accompanied by an absorption of oxygen; and that all those constituents of the blood which possess in any degree the power of combining with oxygen, absorb it in the lungs, and become saturated with it. Although in contact with these other compounds, the globules, when arterialized, retain their florid, red colour in the most minute ramifications of the arteries; and we observe them to change their colour, and to assume the dark red colour which characterizes venous blood, only during their passage through the capillaries. From these facts we must conclude that the constituents of arterial blood are altogether destitute of the power to deprive the arterialized globules of the oxygen which they have absorbed from the air; and we can draw no other conclusion from the change of colour which occurs in the capillaries, than that the arterialized globules, during their passage through the capillaries, return to the condition which characterized them in venous blood; that consequently, they give up the oxygen absorbed in the lungs, and thus acquire the power of combining with that element afresh.

78. We find, therefore, in arterial blood, albumen, which, like all the other constituents of that fluid, has become saturated with oxygen in its passage through the lungs, and oxygen gas, which is conveyed to every particle in the body in chemical combination with the globules of the blood. As far as our observations extend (in the developement of the chick during incubation,) all the conditions seem to be here united which are necessary to the formation of every kind of tissue; while that portion of oxygen which is not consumed in the growth or reproduction of organs combines with the substance of the living parts, and produces, by its union with their elements, the act of transformation which we have called the change of matter.

79. It is obvious, that all compounds, of whatever kind, which are present in the capillaries, whether separated there, or introduced by endosmosis or imbibition, if not altogether incapable of uniting with oxygen, must, when in contact with the arterialized globules, the carriers of oxygen, be affected exactly in the same way as the solids forming part of living organs. These compounds, or their elements, will enter into combination with oxygen, and in this case there will either be no change of matter, or that change will exhibit itself in another form, yielding products of a different kind.

80. The conception, then, of a change in the two qualities of the blood above alluded to, by means of a foreign body contained in the blood or introduced into the circulation (a medicinal agent) presupposes two kinds of operation.

Assuming that the remedy cannot enter into any such chemical union with the constituents of the blood as puts an end to the vital activity; assuming, further, that it is not in a condition of transformation capable of being communicated to the constituents of the blood or of the organs, and of continuing in them; assuming, lastly, that it is incapable, by its contact with the living parts, of putting a stop to the change of matter, the transformation of their elements; then, in order to discover the modus operandi of this class of medicinal agents, nothing is left but to conclude that their elements take a share in the formation of certain constituents of the living body, or in the production of certain secretions.

81. The vital process of secretion, in so far as it is related to the chemical forces, has been subjected to examination in the preceding pages. In the carnivora we have reason to believe, that without the addition of any foreign matter in the food, the bile and the constituents of the urine are formed in those parts where the change of matter takes place. In other classes of animals, on the other hand, we may suppose that in the organ of secretion itself, the secreted fluid is produced from certain matters conveyed to it; in the herbivora, for example, the bile is formed from the elements of starch along with those of a nitrogenized product of the metamorphosis of the tissues. But this supposition by no means excludes the opinion, that in the carnivora the products of the metamorphosed tissues are resolved into bile, uric acid, or urea, only after reaching the secreting organ; nor the opinion that the elements of the non-azotized food, conveyed directly by the circulation to every part of the body, where change of matter is going on, may there unite with the elements of the metamorphosed tissues, to form the constituents of the bile and of the urine.

82. If we now assume, that certain medicinal agents may become constituents of secretions, this can only occur in two ways. Either they enter the circulation, and take a direct share in the change of matter in so far as their elements enter into the composition of the new products; or they are conveyed to the organs of secretion, where they exert an influence on the formation or on the quality of a secretion by the addition of their elements.

In either case, they must lose in the organism their chemical character; and we know with sufficient certainty, that this class of medicinal bodies disappear in the body without leaving a trace. In fact, if we ascribe to them any effect, they cannot lose their peculiar character by the action of the stomach; their disappearance, therefore, presupposes that they have been applied to certain purposes, which cannot be imagined to occur without a change in their composition.

83. Now, however limited may be our knowledge of the composition of the different secretions, with the exception of the bile, this much is certain, that all the secre-

tions contain nitrogen chemically combined. They pass into fetid putrefaction, and yield either in this change, or in the dry distillation, ammoniacal products. Even the saliva, when acted upon by caustic potash, disengages ammonia freely.

84. Medicinal or remedial agents may be divided into two classes, the nitrogenized and the non-nitrogenized. The nitrogenized vegetable principles, whose composition differs from that of the proper nitrogenized elements of nutrition, also produced by a vegetable organism, are distinguished, beyond all others, for their powerful action on the animal economy.

The effects of these substances are singularly varied; from the mildest form of the action of aloes, to the most terrible poison, strychnia, we observe an endless variety of different action.

With the exception of three, all these substances produce diseased conditions in the healthy organism, and are poisonous in certain doses. Most of them are, chemically speaking, basic or alkaline.

No remedy, devoid of nitrogen, possesses a poisonous action in a similar dose.*

85. The medicinal or poisonous action of the nitrogenized vegetable principles has a fixed relation to their composition; it cannot be supposed to be independent of the nitrogen they contain, but is certainly not in direct proportion to the quantity of nitrogen.

Solanine (38,) and picrotoxine (39,) which contain least nitrogen, are powerful poisons. Quinine (40) contains more nitrogen than morphia (41.) Caffeine (42,) and theobromine the most highly nitrogenized of all vegetable principles, are not poisonous.

86. A nitrogenized body, which exerts, by means of its elements, an influence on the formation or on the quality of a secretion, must, in regard to its chemical character, be capable of taking the same share as the nitrogenized products of the animal body do in the formation of the bile; that is, it must play the same part as a product of the vital process. On the other hand, a non-azotized medicinal agent, in so far as its action affects the secretions, must be capable of performing in the animal body the same part as that which we have ascribed in the formation of the bile, to the non-azotized elements of food.

Thus, if we suppose that the elements of hippuric or uric acids are divided from the substance of the organs in which vitality resides; that as products of the transformation of these organs they lose the vital character, without losing the capacity of undergoing changes under the influence of the inspired oxygen, or of the apparatus of secretion; we can hardly doubt that similar nitrogenized compounds, products of the vital process in plants, when introduced into the animal body, may be employed by the organism exactly in the same way as the nitrogenized products of the metamorphosis of the animal tissues themselves. If hippuric and uric acids, or any of their elements, can take a share, for example, in the formation and supply of bile, we must allow the same power to other analogous nitrogenized compounds.

We shall never, certainly, be able to discover how men were led to the use of the hot infusion of the leaves of a certain shrub (tea) or of a decoction of certain roasted seeds (coffee.) Some cause there must be, which would explain how the practice has become a necessary of life to whole nations. But it is surely still more remarkable, that the beneficial effects of both plants on the health must be ascribed to one and the same substance, the presence of which in two vegetables, belonging to different natural families, and the produce of different quarters of the globe, could hardly have presented itself to the boldest imagination. Yet recent researches have shown, in such a manner as to exclude all doubt, that caffeine, the peculiar principle of coffee, and theine, that of tea, are, in all respects, identical.

It is not less worthy of notice, that the American Indian, living entirely on flesh, discovered for himself, in tobacco smoke, a means of retarding the change of matter in the tissues of his body, and thereby of making hunger more endurable; and that he cannot withstand the action of brandy, which, acting as an element of respiration, puts a stop to the change of matter by performing the function which properly belongs to the products of the metamorphosed tissues. Tea and coffee were originally met with among nations whose diet is chiefly vegetable.

87. Without entering minutely into the medicinal action of caffeine, (theine,) it will surely appear a most striking fact, even if we were to deny its influence on the process of secretion, that this substance, with the addition of oxygen and the elements of water, can yield taurine, the nitrogenized compound peculiar to bile:

$$\begin{array}{lcr} \text{1 at. caffeine or theine} & = & C^8N^2H^5O^2 \\ \text{9 at. water} \quad - & = & H^9O^9 \\ \text{9 at. oxygen} \quad - & = & O^9 \\ \hline & & C^8N^2H^{14}O^{20} = \\ =\text{2 at. taurine} \quad - & = & 2(C^4NH^7O^{10}) \end{array}$$

A similar relation exists in the case of the peculiar principle of asparagus and of althæa, asparagine; which also, by the addition of oxygen and the elements of water, yields the elements of taurine.

$$\begin{array}{lcr} \text{1 at. asparagine} & = & C^8N^2H^8O^6 \\ \text{6 at. water} \quad - & = & H^6O^6 \\ \text{8 at. oxygen} & = & O^8 \\ \hline & & C^8N^2H^{14}O^{20} = \\ =\text{2 at. taurine} & = & (C^4NH^7O^{10} \end{array}$$

The addition of the elements of water and

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* This consideration or comparative view has led lately to a more accurate investigation of the composition of picrotoxine, the poisonous principle of cocculus indicus; and M. Francis has discovered the existence of nitrogen in it, hitherto overlooked, and has also determined its amount.

of a certain quantity of oxygen to the elements of theobromine, the characteristic principle of the cacao bean, (theobroma cacao,) yields the elements of taurine and urea, of taurine, carbonic acid, and ammonia, or of taurine and uric acid:

$$\left.\begin{array}{lr} \text{1 at. theobromine} & C^{18}N^6H^{10}O^4 \\ \text{22 at. water} \quad - & H^{22}O^{22} \\ \text{16 at. oxygen} \quad - \quad - & O^{16} \end{array}\right\} = $$

$$\begin{array}{r} \hline C^{18}N^6H^{32}O^{42} \end{array}$$

$$=\left\{\begin{array}{lr} \text{4 at. taurine} \quad - & C^{16}N^4H^{28}O^{40} \\ \text{1 at. urea} \quad - & C^2N^2H^4O^2 \\ \hline & C^{18}N^6H^{32}O^{42} \end{array}\right.$$

or—

$$\left.\begin{array}{lr} \text{1 at. theobromine} & C^{18}N^6H^{10}O^4 \\ \text{24 at. water} \quad - & H^{24}O^{24} \\ \text{16 at. oxygen} \quad - & O^{16} \end{array}\right\} = $$

$$\begin{array}{r} \hline C^{18}N^6H^{34}O^{44} \end{array}$$

$$=\left\{\begin{array}{lr} \text{4 at. taurine} & C^{16}N^4H^{28}O^{40} \\ \text{2 at. carbonic acid} & C^2 \quad O^4 \\ \text{2 at. ammonia} & N^2H^6 \\ \hline & C^{18}N^6H^{34}O^{44} \end{array}\right.$$

or—

$$\left.\begin{array}{lr} \text{1 at. theobromine} & C^{18}N^6H^{10}O^4 \\ \text{8 at. water} \quad - & H^8O^8 \\ \text{14 at. oxygen} \quad - & O^{14} \end{array}\right\} = $$

$$\begin{array}{r} \hline C^{18}N^6H^{18}O^{26} \end{array}$$

$$=\left\{\begin{array}{lr} \text{2 at. taurine} & C^8N^2H^{14}O^{20} \\ \text{1 at. uric acid} & C^{10}N^4H^4O^6 \\ \hline & C^{18}N^6H^{18}O^{26} \end{array}\right.$$

88. To see how the action of caffeine, asparagine, theobromine, &c., may be explained, we must call to mind that the chief constituent of the bile contains only 3·8 per cent. of nitrogen, of which only the half, or 1·9 per cent., belongs to the taurine.

Bile contains, in its natural state, water and solid matter, in the proportion of 90 parts by weight of the former to 10 of the latter. If we suppose these 10 parts by weight of solid matter to be choleic acid, with 3·87 per cent. of nitrogen, then 100 parts of fresh bile will contain 0·171 parts of nitrogen in the shape of taurine. Now this quantity is contained in 0·6 parts of caffeine: or 2$\frac{8}{10}$ths grains of caffeine can give to an ounce of bile the nitrogen it contains in the form of taurine. If an infusion of tea contain no more than the $\frac{1}{10}$th of a grain of caffeine, still, if it contribute in point of fact to the formation of bile, the action, even of such a quantity, cannot be looked upon as a nullity. Neither can it be denied that in the case of an excess of non-azotized food and a deficiency of motion, which is required to cause the change of matter in the tissues, and thus to yield the nitrogenized product which enters into the composition of the bile; that in such a condition, the health may be benefited by the use of compounds which are capable of supplying the place of the nitrogenized product produced in the healthy state of the body, and essential to the production of an important element of respiration. In a chemical sense—and it is this alone which the preceding remarks are intended to show—caffeine or theine, asparagine, and theobromine are in virtue of their composition better adapted to this purpose than all other nitrogenized vegetable principles. The action of these substances, in ordinary circumstances, is not obvious, but it unquestionably exists.

89. With respect to the action of the other nitrogenized vegetable principles, such as quinine, or the alkaloids of opium, &c., which manifests itself, not in the processes of secretion, but in phenomena of another kind, physiologists and pathologists entertain no doubt that it is exerted chiefly on the brain and nerves. This action is commonly said to be dynamic—that is, it accelerates, or retards, or alters in some way the phenomena of motion in animal life. If we reflect that this action is exerted by substances which are material, tangible and ponderable; that they disappear in the organism; that a double dose acts more powerfully than a single one; that, after a time, a fresh dose must be given, if we wish to produce the action a second time; all these considerations, viewed chemically, permit only one form of explanation; the supposition, namely, that these compounds, by means of their elements, take a share in the formation of new, or the transformation of existing brain and nervous matter.

However strange the idea may, at first sight, appear, that the alkaloids of opium or of cinchona bark, the elements of codeine, morphia, quinine, &c., may be converted into constituents of brain and nervous matter, into organs of vital energy, from which the organic motions of the body derive their origin; that these substances form a constituent of that matter, by the removal of which the seat of intellectual life, of sensation, and of consciousness, is annihilated; it is nevertheless certain, that all these forms of power and activity are most closely dependent, not only on the existence, but also on a certain quality of the substance of the brain, spinal marrow, and nerves; insomuch that all the manifestations of the life or vital energy of these modifications of nervous matter, which are recognized as the phenomena of motion, sensation, or feeling, assume another form as soon as their composition is altered. The animal organism has produced the brain and nerves out of compounds furnished to it by vegetables; it is the constituents of the food of the animal, which, in consequence of a series of changes, have assumed the properties and the structure which we find in the brain and nerves.

90. If it must be admitted as an undeniable truth, that the substance of the brain and nerves is produced from the elements of vegetable albumen, fibrine and caseine, either alone, or with the aid of the elements of non-azotized food or of the fat formed from the latter, there is nothing absurd in the opinion, that other constituents of vege

tables, intermediate in composition between the fats and the compounds of proteine, may be applied in the organism to the same purpose.

91. According to the researches of Fremy, the chief constituent of the fat found in the brain is a compound of soda with a peculiar acid, the ***cerebric acid,*** which contains, in 100 parts,

Carbon	66·7
Hydrogen	10·6
Nitrogen	2·3
Phosphorus	0·9
Oxygen	19·5

It is easy to see that the composition of cerebric acid differs entirely, both from that of ordinary fats and of the compounds of proteine. Common fats contain no nitrogen, while the compounds of proteine contain nearly 17 per cent. Leaving the phosphorus out of view, the composition of this acid approaches most nearly to that of choleic acid, although these two compounds are quite distinct.

92. Brain and nervous matter is, at all events, formed in a manner similar to that in which bile is produced; either by the separation of a highly nitrogenized compound from the elements of blood, or by the combination of a nitrogenized product of the vital process with a non-azotized compound (probably, a fatty body.) All that has been said in the preceding pages on the various possible ways by which the bile might be supposed to be formed, all the conclusions which we attained in regard to the co-operation of azotized and non-azotized elements of food, may be applied with equal justice and equal probability to the formation and production of the nervous substance.

We must not forget that, in whatever light we may view the vital operations, the production of nervous matter from blood presupposes a change in the composition and qualities of the constituents of blood. That such a change occurs is as certain as that the existence of the nervous matter cannot be denied. In this sense, we must assume, that from a compound of proteine may be formed a first, second, third, &c., product before a certain number of its elements can become constituents of the nervous matter; and it must be considered as quite certain, that a product of the vital process in a plant, introduced into the blood, will, if its composition be adapted to this purpose, supply the place of the first, second, or third product of the alteration of the compound of proteine. Indeed it cannot be considered merely accidental, that the composition of the most active remedies, namely, the vegetable alkaloids, cannot be shown to be related to that of any constituent of the body, except only the substance of the nerves and brain. All of these contain a certain quantity of nitrogen, and, in regard to their composition, they are intermediate between the compounds of proteine and the fats.

93. In contradistinction to their chemical character, we find that the substance of the brain exhibits the characters of an acid. It contains far more oxygen than the organic basis or alkaloids. We observe, that quinine and cinchonine, morphia and codeine, strychnia and brucia, which are, respectively, so nearly alike in composition, if they do not produce absolutely the same effect, yet resemble each other in their action more than those which differ more widely in composition. We find that their energy of action diminishes, as the amount of oxygen they contain increases (as in the case of narcotine,) and that, strictly speaking, no one of them can be entirely replaced by another. There cannot be a more decisive proof of the nature of their action than this last fact; it must stand in the closest relation to their composition. If these compounds, in point of fact, are capable of taking a share in the formation or in the alteration of the qualities of brain and nervous matter, their action on the healthy as well as the deceased organism admits of a surprisingly simple explanation. If we are not tempted to deny, that the chief constituent of soup may be applied to a purpose corresponding to its composition in the human body, or that the organic constituent of bones may be so employed in the body of the dog, although that substance (gelantine in both cases) is absolutely incapable of yielding blood; if, therefore, nitrogenized compounds, totally different from the compounds of proteine, may be employed for purposes corresponding to their composition; we may thence conclude that a product of vegetable life, also different from proteine, but similar to a constituent of the animal body, may be employed by the organism in the same way and for the same purpose as the natural product, originally formed by the vital energy of the animal organs, and that indeed from a vegetable substance.

The time is not long gone by, when we had not the very slightest conception of the cause of the various effects of opium, and when the action of cinchona bark was shrouded in incomprehensible obscurity. Now that we know that these effects are caused by crystallizable compounds, which differ as much in composition as in their action on the system; now that we know the substances to which the medicinal or poisonous energy must be ascribed, it would argue only want of sense to consider the action of these substances inexplicable; and to do so, as many have done, because they act in very minute doses, is as unreasonable as it would be to judge of the sharpness of a razor by its weight.

94. It would serve no purpose to give these considerations a greater extension at present. However hypothetical they may appear, they only deserve attention in so far

as they point out the way which chemistry pursues, and which she ought not to quit, if she would really be of service to physiology and pathology. The combinations of the chemist relate to the change of matter, forwards and backwards, to the conversion of food into the various tissues and secretions, and to their metamorphosis into lifeless compounds; his investigations ought to tell us what has taken place and what can take place in the body. It is singular that we find medicinal agencies all dependent on certain matters, which differ in composition; and if, by the introduction of a substance, certain abnormal conditions are rendered normal, it will be impossible to reject the opinion, that this phenomenon depends on a change in the composition of the constituents of the diseased organism, a change in which the elements of the remedy take a share; a share similar to that which the vegetable elements of food have taken in the formation of fat, of membranes, of the saliva, of the seminal fluid, &c. Their carbon, hydrogen, or nitrogen, or whatever else belongs to their composition, are derived from the vegetable organism; and, after all, the action and effects of quinine, morphia, and the vegetable poisons in general, are no hypotheses.

95. Thus, as we may say, in a certain sense, of caffeine, or theine, and asparagine, &c., as well as of the non-azotized elements of food, that they are food for the liver, since they contain the elements, by the presence of which that organ is enabled to perform its functions, so we may consider these nitrogenized compounds, so remarkable for their action on the brain and on the substance of the organs of motion, as elements of food for the organs as yet unknown, which are destined for the metamorphosis of the constituents of the blood into nervous substance and brain. Such organs there must be in the animal body, and if, in the diseased state, an abnormal process of production or transformation of the constituents of cerebral and nervous matter has been established; if, in the organs intended for this purpose, the power of forming that matter out of the constituents of blood, or the power of resisting an abnormal degree of activity in its decomposition or transformation, has been diminished; then, in a chemical sense, there is no objection to the opinion, that substances of a composition analogous to that of nervous or cerebral matter, and, consequently, adapted to form that matter, may be employed, instead of the substances produced from the blood, either to furnish the necessary resistance, or to restore the normal condition.

96. Some physiologists and chemists have expressed doubts of the peculiar and distinct character of cerebric acid, a substance which, from its amount of carbon and hydrogen, and from its external characters, resembles a nitrogenized fatty acid. But a nitrogenized fat, having an acid character, is, in fact, no anomaly. Hippuric acid is in many of its characters very similar to the fatty acids, but is essentially distinguished from them by containing nitrogen. The organic constituents of bile resemble the acid resins in physical characters, and yet contain nitrogen. The organic alkalies are intermediate in their physical characters between the fats and resins, and they all contain nitrogen. A nitrogenized fatty acid is as little improbable as the existence of a nitrogenized resin with the characters of a base.

97. An accurate investigation would probably discover differences in the composition of the brain, spinal marrow and nerves. According to the observations of Valentin, the quality of the cerebral and nervous substance is very rapidly altered from the period of death, and very uncommon precautions would be required for the separation of foreign matters not properly belonging to the substance of the spinal marrow or brain. But, however difficult it may appear, the investigation seems yet to be practicable. We know, in the meantime, that all experience is against the notion of a large amount of carbon and hydrogen in the substance of the brain. The absence of nitrogen as an element of the cerebral and nervous matter, appears, at all events, improbable. This substance, moreover, cannot be classed with ordinary fats, because we find the cerebric acid combined with soda, whereas, all fats are compounds of fatty acids with oxide of glycerule. In regard to the phosphorus of the brain, we can only guess as to the form in which the phosphorus exists. Walchner observed recently that bubbles of spontaneously inflammable phosphuretted hydrogen were disengaged from the trough of a spring in Carlsruhe, on the bottom of which fish had putrefied; and gases containing phosphorus have also been observed among the products of the putrefaction of the brain.*

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* The curator of the museum at Geneva gave to M. Leroyer, apothecary, a large quantity of spirit of wine, which had been used for the preservation of fishes, and which he undertook to purify. He distilled from it a mixture of chloride of calcium and quicklime, and evaporated the residue in the air, over a fire. As soon as the mass had acquired a certain consistence, and a higher temperature, a prodigious quantity of spontaneously inflammable phosphoretted hydrogen was disengaged. (Dumas. V. 267.)

PART III.

THE PHENOMENA OF MOTION IN THE ANIMAL ORGANISM.

I. It might appear an unprofitable task to add one more to the innumerable forms under which the human intellect has viewed the nature and essence of that peculiar cause which must be considered as the ultimate source of the phenomena which characterize vegetable and animal life, were it not that certain conceptions present themselves as necessary deductions from the views on this subject developed in the introduction to the first part of this work. The following pages will be devoted to a more detailed examination of these deductions. It must be admitted here, that all these conclusions will lose their force and significance, if it can be proved that the cause of vital activity has in its manifestations nothing in common with other known causes which produce motion or change of form and structure in matter.

But a comparison of its peculiarities with the modus operandi of these other causes, cannot, at all events, fail to be advantageous, inasmuch as the nature and essence of natural phenomena are recognizable, not by abstraction, but only by comparative observations.

If the vital phenomena be considered as manifestations of a peculiar force, then the effects of this force must be regulated by certain laws, which laws may be investigated; and these laws must be in harmony with the universal laws of resistance and motion, which preserve in their courses the worlds of our own and other systems, and which also determine changes of form and structure in material bodies; altogether independently of the matter in which vital activity appears to reside, or of the form in which vitality is manifested.

The vital force in a living animal tissue appears as a cause of growth in the mass, and of resistance to those external agencies which tend to alter the form, structure, and composition of the substance of the tissue in which the vital energy resides.

This force further manifests itself as a cause of motion and of change in the form and structure of material substances, by the disturbance and abolition of the state of rest in which those chemical forces exist, by which the elements of the compounds conveyed to the living tissues, in the form of food, are held together.

The vital force causes a decomposition of the constituents of food, and destroys the force of attraction which is continually exerted between their molecules; it alters the direction of the chemical forces in such wise, that the elements of the constituents of food arrange themselves in another form, and combine to produce new compounds, either identical in composition with the living tissues, or differing from them; it further changes the direction and force of the attraction of cohesion, destroys the cohesion of the nutritious compounds, and forces the new compounds to assume forms altogether different from those which are the result of the attraction of cohesion when acting freely, that is, without resistance.

The vital force is also manifested as a force of attraction, inasmuch as the new compound produced by the change of form and structure in the food, when it has a composition identical with that of the living tissue, becomes a part of that tissue.

Those newly-formed compounds, whose composition differs from that of the living tissue, are removed from the situation in which they are formed, and, in the shape of certain secretions, being carried to other parts of the body, undergo in contact with these a series of analogous changes.

The vital force is manifested in the form of resistance, inasmuch as by its presence in the living tissues, their elements acquire the power of withstanding the disturbance and change in their form and composition, which external agencies tend to produce; a power which, simply as chemical compounds, they do not possess.

As in the case of other forces, the conception of an unequal intensity of the vital force comprehends not only an unequal capacity for growth in the mass and an unequal power of overcoming chemical resistance, but also an inequality in the amount of that resistance which the parts or constituents of the living tissue oppose to a change in their form and composition, from the action of new external active causes of change; just as the force of cohesion or of affinity is in direct proportion to the resistance which these forces oppose to any external cause, mechanical or chemical, tending to separate the molecules, or the elements of an existing compound.

The manifestations of the vital force are dependent on a certain form of the tissue in which it resides, as well as on a fixed composition in the substance of the living tissue.

The capacity of growth in a living tissue is determined by the immediate contact with matters adapted to a certain decomposition, or the elements of which are capable of becoming component parts of the tissue in which vitality resides.

The phenomenon of growth, or increase in the mass, presupposes that the acting vital force is more powerful that the resistance which the chemical force opposes to the decomposition or transformation of the elements of the food.

The manifestations of the vital force are dependent on a certain temperature. Neither in a plant nor in an animal do vital phenomena occur when the temperature is lowered to a certain extent.

The phenomena of vitality in a living organism diminish in intensity when heat is abstracted, provided the lost heat be not restored by other causes.

Deprivation of food soon puts a stop to all manifestations of vitality.

The contact of the living tissues with the elements of nutrition is determined in the animal body by a mechanical force produced within the body, which gives to certain organs the power of causing change of place, of producing motion, and of overcoming mechanical resistance.

We may communicate motion to a body at rest by means of a number of forces, very different in their manifestations. Thus, a time-piece may be set in motion by a falling weight, (gravitation,) or by a bent spring (elasticity.) Every kind of motion may be produced by the electric or magnetic force, as well as by chemical attraction; while we cannot say, as long as we only consider the manifestation of these forces in the phenomenon or result produced, which of these various causes of change of place has set the body in motion.

In the animal organism we are acquainted with only one cause of motion; and this is the same cause which determines the growth of living tissues, and gives them the power of resistance to external agencies; it is the vital force.

In order to attain a clear conception of these manifestations of the vital force, so different in form, we must bear in mind, that every known force is recognized by two conditions of activity, entirely different in the phenomena they offer to the attention of the observer.

The force of gravitation inherent in the particles of a stone, gives to them a continual tendency to move towards the centre of the earth.

This effect of gravitation becomes inappreciable to the senses when the stone, for example, rests upon a table, the particles of which oppose a resistance to the manifestation of its gravitation. The force of gravity, however, is constantly present, and manifests itself as a pressure on the supporting body; but the stone remains at rest; it has no motion. The manifestation of gravity in the state of rest we call its weight.

That which prevents the stone from falling is a resistance produced by the force of attraction, by which the particles of the wood cohere together; a mass of water would not prevent the fall of the stone.

If the force which impelled the mass of the stone towards the centre of the earth were greater than the force of cohesion in the particles of the wood, the latter would be overcome; it would be unable to prevent the fall of the stone.

When we remove the support, and with it the force which has prevented the manifestation of the force of gravity, the latter at once appears as the cause of change of place in the stone, which acquires motion, or falls. Resistance is invariably the result of a force in action.

According as the stone is allowed to fall during a longer or shorter time, it acquires properties which it had not while at rest; it acquires, for example, the power of overcoming more feeble or more powerful obstacles, or that of communicating motion to bodies in a state of rest.

If it fall from a certain height it makes a permanent impression on the spot on which it falls; if it fall from a still greater height (during a longer time) it perforates the table; its own motion is communicated to a certain number of the particles of the wood which now fall along with the stone itself. The stone, while at rest, possessed none of these properties.

The velocity of the falling body is always the effect of the moving force, and is, ceteris paribus, proportional to the force of gravitation.

A body, falling freely, acquires at the end of one second a velocity of 30 feet. The same body, if falling on the moon, would acquire in one second only a velocity of $\frac{30}{360}$th of a foot=1 inch, because in the moon the intensity of gravitation (the pressure acting on the body, the moving power) is 360 times smaller.

If the pressure continue uniform, the velocity is directly proportional to it; so that, for example, the body falling 360 times slower, will, after 360 seconds, have the same velocity as the other body after one second.

Consequently, the effect is proportional, not to the moving force alone, nor to the time alone, but to the pressure multiplied into the time, which is called the *momentum of force.*

In two equal masses the velocity expresses the momentum of force. But under the same pressure a body moves more slowly as its mass is greater; a mass twice as great requires, in order to attain in the same time an equal velocity, twice the pressure; or, under the single pressure, it must continue in motion twice as long.

In order, therefore, to have an expression for the whole effect produced, we must multiply the mass into the velocity. This product is called the *amount of motion.*

The amount of motion in a given body must in all cases correspond exactly to the momentum of force.

These two, the amount of motion and the momentum of force, are also called simply *force;* because we suppose that a less pressure acting, for example, during 10 seconds, is equal to a pressure ten times greater, acting only during one second.

The *momentum of motion* in mechanics signifies the effect of a moving force, without reference to the time (velocity) in which it was manifested. If one man, for example, raises 30 lbs. to a height of 100 feet, and a second one 30 lbs. to a height of 200 feet; then the latter has expended twice as much force as the former. A third who raises 60 lbs. to a height of 50 feet, expends no more force than the first did in raising 30 lbs. to the height of 100 feet. The momentum of motion of the first (30×100) is equal to that of the third (60×50) while that of the second (30×200) is twice as great.

Momentum of force and momentum of motion in mechanics are therefore expressions or measures for effects of force, having reference to the velocity attained in a given time, or to a given space; and in this sense may be applied to the effects of all other causes of motion, or of change in form and structure, however great or however small may be the space or the time in which their effects are displayed to the senses.

Every force, therefore, exhibits itself in matter either in the form of resistance to external causes of motion, or of change in form and structure; or as a moving force when no resistance is opposed to it; or, finally, in overcoming resistance.

One and the same force communicates motion and destroys motion; the former when its manifestations are opposed by no resistance; the latter, when it puts a stop to the manifestation of some other cause of motion, or of change in form and structure. Equilibrium or rest is that state of activity in which one force or momentum of motion is destroyed by an opposite force or momentum of motion.

We observe both these manifestations of activity in that force which gives to the living tissues their peculiar properties.

The vital force appears as a moving force or cause of motion when it overcomes the chemical forces (cohesion and affinity) which act between the constituents of food, and when it changes the position or place in which their elements occur; it is manifested as a cause of motion in overcoming the chemical attraction of the constituents of food, and is, further, the cause which compels them to combine in a new arrangement, and to assume new forms.

It is plain that a part of the animal body possessed of vitality, which has therefore the power of overcoming resistance, and of giving motion to the elementary particles of the food, by means of the vital force manifested in itself must have a momentum of motion, which is nothing else than the measure of the resulting motion or change in form and structure.

We know that this momentum of motion in the vital force, residing in a living part, may be employed in giving motion to bodies at rest, (that is, in causing decomposition, or overcoming resistance,) and if the vital force is analogous in its manifestations to other forces, this momentum of motion must be capable of being conveyed or communicated by matters, which in themselves do not destroy its effect by an opposite manifestation of force.

Motion, by whatever cause produced, cannot in itself be annihilated; it may indeed become inappreciable to the senses, but even when arrested by resistance (by the manifestation of an opposite force,) its effect is not annihilated. The falling stone, by means of the amount of motion acquired in its descent, produces an effect when it reaches the table. The impression made on the wood, the velocity communicated by its parts to those of the wood, all this is its effect.

If we transfer the conceptions of motion, equilibrium, and resistance, to the chemical forces, which, in their modus operandi, approach to the vital force infinitely nearer than gravitation does, we know with the utmost certainty, that they are active only in the case of immediate contact. We know, also, that the unequal capacity of chemical compounds to offer resistance to external disturbing influences, to those of heat, or of electricity, which tend to separate their particles, as well as their power of overcoming resistance in other compounds (of causing decomposition); that, in a word, the active force in a compound depends on a certain order or arrangement, in which its elementary particles touch each other.

The same elements, united in a different order, when in contact with other compounds, exert a most unequal power of offering or overcoming resistance. In one form the force manifested is available (the body is active, an acid, for example); in another not (the body is indifferent, neutral); in a third form, the momentum of force is opposed to that of the first (the body is active, but a base).

If we alter the arrangement of the elements, we are able to separate the constituents of a compound by means of another active body; while the same elements, united in their original order, would have opposed an invincible resistance to the action of the decomposing agent.

In the same way as two equal inelastic masses, impelled with equal velocity from opposite points, on coming into contact are brought to rest; in the same way, therefore, as two equal and opposite momenta of motion mutually destroy each other; so may the momentum of force in a chemical compound be destroyed in whole or in part by an equal or unequal, and opposite momentum of force in a second compound. But it cannot be annihilated as long as the arrangement of the elementary particles, by which its inherent force was manifested, is not changed.

The chemical force of sulphuric acid is present in sulphate of lime as entire as in oil of vitriol. It is not appreciable by the senses; but if the cause be removed which prevented its manifestation, it appears in its full force in the compound in which it properly resides.

Thus the force of cohesion in a solid may disappear, to the senses, from the action of a chemical force, (in solution,) or of heat

(in fusion,) without being in reality annihilated or even weakened. If we remove the opposing force or resistance, the force of cohesion appears unchanged in crystallization.

By means of the electrical force, or that of heat, we can give the most varied directions to the manifestations of chemical force. By these means we can fix, as it were, the order in which the elementary particles shall unite. Let us remove the cause (heat or electricity) which has turned the balance in favour of the weaker attraction in one direction, and the stronger attraction will show itself continually active in another direction; and if this stronger attraction can overcome the vis inertiæ of the elementary particles, they will unite in a new form, and a new compound of different properties must be the result.

In compounds of this kind, in which, therefore, the free manifestation of the chemical force has been impeded by other forces, a blow, or mechanical friction, or the contact of a substance, the particles of which are in a state of motion (decomposition, transformation,) or any external cause, whose activity is added to the stronger attraction of the elementary particles in another direction, may suffice to give the preponderance to this stronger attraction, to overcome the vis inertiæ, to alter the form and structure of the compound, which are the result of foreign causes, and to produce the resolution of the compound into one or more new compounds with altered properties

Transformations, or as they may be called, phenomena of motion, in compounds of this class, may be effected by means of the free and available chemical force of another chemical compound, and that without its manifestation being enfeebled or arrested by resistance. Thus the equilibrium in the attraction between the elements of cane-sugar is destroyed by contact with a very small quantity of sulphuric acid, and it is converted into grape-sugar. In the same way we see the elements of starch, under the same influence, arrange themselves with those of water in a new form, while the sulphuric acid, which has served to produce these transformations, loses nothing of its chemical character. In regard to other substances on which it acts, it remains as active as before, exactly as if it had exerted no sort of influence on the cane-sugar or starch.

In contradistinction to the manifestions of the so-called mechanical forces, we have recognized in the chemical forces causes of motion and of change in form and structure, without any observable exhaustion of the force by which these phenomena are produced; but the origin of the continued manifestation of activity remains still the same; it is the absence of an opposite force (a resistance) capable of neutralizing it or bringing it into the state of equilibrium.

As the manifestations of chemical forces (the momentum of force in a chemical compound) seem to depend on a certain order in which the elementary particles are united together, so experience tells us, that the vital phenomena are inseparable from matter; that the manifestations of the vital force in a living part are determined by a certain form of that part, and by a certain arrangement of its elementary particles. If we destroy the form, or alter the composition of the organ, all manifestations of vitality disappear.

There is nothing to prevent us from considering the vital force as a peculiar property, which is possessed by certain material bodies, and becomes sensible when their elementary particles are combined in a certain arrangement or form.

This supposition takes from the vital phenomena nothing of their wonderful peculiarity; it may therefore be considered as a resting point, from which an investigation into these phenomena, and the laws which regulate them, may be commenced; exactly as we consider the properties and laws of light to be dependent on a certain luminiferous matter, or other, which has no further connexion with the laws ascertained by investigation.

Considered under this form, the vital force unites in its manifestations all the peculiarities of chemical forces, and of the not less wonderful cause, which we regard as the ultimate origin of electrical phenomena.

The vital force does not act, like the force of gravitation or the magnetic force, at infinite distances, but, like chemical forces, it is active only in the case of immediate contact. It becomes sensible by means of an aggregation of material particles.

A living part acquires, on the above supposition, the capacity of offering and of overcoming resistance, by the combination of its elementary particles in a certain form; and as long as its form and composition are not destroyed by opposing forces, it must retain its energy uninterrupted and unimpaired.

When, by the act of manifestation of this energy in a living part, the elements of the food are made to unite in the same form and structure as the living organ possesses, then these elements acquire the same powers. By this combination, the vital force inherent in them is enabled to manifest itself freely, and may be applied in the same way as that of the previously existing tissue.

If, now, we bear in mind, that all matters which serve as food to living organisms are compounds of two or more elements, which are kept together by certain chemical forces; if we reflect that in the act of manifestation of force in a living tissue, the elements of the food are made to combine in a new order;—it is quite certain that the momentum of force or of motion in the vital force was more powerful than the chemical attraction existing between the elements of the food.*

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* The hands of a man, who raises with a rope

The chemical force which kept the elements together acted as a resistance, which was overcome by the active vital force.

Had both forces been equal, no kind of sensible effect would have ensued. Had the chemical force been the stronger, the living part would have undergone a change.

If we now suppose that a certain amount of vital force must have been expended in bringing to an equilibrium the chemical force, there must still remain an excess of force, by which the decomposition was effected. This excess constitutes the momentum of force in the living part, by means of which the change was produced; by means of this excess the part acquires a permanent power of causing further decompositions, and of retaining its condition, form, and structure, in opposition to external agencies.

We may imagine this excess to be removed, and employed in some other form. This would not of itself endanger the existence of the living part, because the opposing forces would be left in equilibrio; but, by the removal of the excess of force, the part would lose its capacity of growth, its power to cause further decompositions, and its ability to resist external causes of change. If, in this state of equilibrium, oxygen (a chemical agent) should be brought in contact with it, then there would be no resistance to the tendency of the oxygen to combine with some element of the living part, because its power of resistance has been taken away by some other application of its excess of vital force. According to the amount of oxygen brought to it, a certain proportion of the living part would lose its condition of vitality, and take the form of a chemical combination, having a composition different from that of the living tissue. In a word, there would occur a change in the properties of the living compound, or what we have called a change of matter.

If we reflect that the capacity of growth or increase of mass in plants is almost unlimited; that a hundred twigs from a willow tree, if placed in the soil, become a hundred trees; we can hardly entertain a doubt, that with the combination of the elements of the food of the plant so as to form a part of it, a fresh momentum of force is added in the newly formed part to the previously existing momentum in the plant; insomuch, that with the increase of mass, the sum of vital force is augmented.

According to the amount of available vital force, the products formed by its activity from the food are varied. The composition of the buds, of the radical fibres, of the leaf, of the flower, and of the fruit, are very different one from the other; and the chemical force by which their elements are held together is very different in each of these cases.

Of the non-azotized constituents of plants we may assert, that no part of the momentum of force is expended in maintaining their form and structure, when their elements have once combined in that order in which they become parts of organs endued with vitality.

Very different is the character of the azotized vegetable principles; for, when separated from the plant, they pass, as is commonly said, spontaneously, into fermentation and putrefaction. The cause of this decomposition or transformation of their elements is the chemical action which the oxygen of the atmosphere exercises on one of their constituents. Now we know, that as long as the plant exhibits the phenomena of life, oxygen gas is given off from its surface; that this oxygen is altogether without action on the constituents of the living plant, for which, in other circumstances, it has the strongest attraction. It is obvious, therefore, that a certain amount of vital force must be expended, partly to retain the elements of the complex azotized principles in the form, order, and structure which belong to them; and partly as a means of resistance against the incessant tendency of the oxygen of the atmosphere to act on their elements, as well as against that of the oxygen separated in the organism of the plant by the vital process.

With the increase of these easily altered compounds, in the flower and in the fruit, for example, the sum of chemical force (the free manifestation of which, counteracted by an equal measure of vital force, is employed to furnish resistance) also increases.

The plant increases in mass until the vital force inherent in it comes into equilibrium with all the other causes opposed to its manifestation. From this period, every new cause of disturbance, added to those previously existing (a change of temperature, for example,) deprives it of the power of offering resistance, and it dies down.

In perennial plants (in trees, for example,) the mass of the easily decomposable (azotized) compounds, compared with that of the non-azotized, is so small, that of the whole sum of force, only a minimum is expended as resistance. In animals, this proportion is reversed.

During every period of the life of a plant, the available vital force (that which is not neutralized by resistance) is expended only in one form of vital manifestation, that of growth or increase of mass, or the overcoming of resistance. No part of this force is applied to other purposes.

In the animal organism, the vital force exhibits itself, as in the plant, in the form of the capacity of growth, and as the means of resistance to external agencies; but both

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and simple pulley, 30 lbs. to the height of 100 feet, pass over a space of 100 feet, while his muscular energy furnishes the equilibrium to a pressure of 30 lbs. Were the force which the man could exert not greater than would suffice to keep in equilibrium a pressure of 30 lbs., he would be unable to raise the weight to the height mentioned.

of these manifestations are confined within certain limits.

We observe in animals, that the conversion of food into blood, and the contact of the blood with the living tissues, are determined by a mechanical force, whose manifestation proceeds from distinct organs, and is effected by a distinct system of organs, possessing the property of communicating and extending the motion which they receive. We find the power of the animal to change its place and to produce mechanical effects by means of its limbs, dependent on a second similar system of organs or apparatus. Both of these systems of apparatus, as well as the phenomena of motion proceeding from them, are wanting in plants.

In order to form a clear conception of the origin and source of the mechanical motions in the animal body, it may be advantageous to reflect on the modus operandi of other forces, which in their manifestations are most closely allied to the vital force.

When a number of plates of zinc and copper, arranged in a certain order, are brought into contact with an acid, and when the extremities of the apparatus are joined by means of a metallic wire, a chemical action begins at the surface of the plates of zinc, and the wire, in consequence of this action, acquires the most singular and wonderful properties.

The wire appears as the carrier or conductor of a force, which may be conducted and communicated through it in every direction with amazing velocity. It is the conductor or propagator of an uninterrupted series of manifestations of activity.

Such a propagation of motion is inconceivable, if in the wire there were a resistance to be overcome; for every resistance would convert a part of the moving force into a force at rest.

When the wire is divided in the middle, and its continuity interrupted, the propagation of force ceases, and we observe, that in this case the action between the zinc and the acid is immediately stopped.

If the communication be restored, the action which had disappeared reappears with all its original energy.

By means of the force present in the wire, we can produce the most varied effects; we can overcome all kinds of resistance, raise weights, set ships in motion, &c. And, what is still more remarkable, the wire acts as a hollow tube, in which a current of chemical force circulates freely and without hindrance.

Those properties which, when firmly attached to certain bodies, we call the strongest and most energetic affinities, we find, to all appearance, free and uncombined in the wire. We can transport them from the wire to other bodies, and thereby give to them an affinity (a power of entering into combination) which in themselves they do not possess. According to the amount of force circulating in the wire, we are able by means of it to decompose compounds, the elements of which have the strongest attraction for each other. Yet the substance of the wire takes not the smallest share in all these manifestations of force; it is merely the conductor of force.

We observe, further, in this wire, phenomena of attraction and repulsion, which we must ascribe to the disturbance of the equilibrium in the electric or magnetic force; and when this equilibrium is restored, the restoration is accompanied by the developement of light and heat, its never-failing companions.

All these remarkable phenomena are produced by the chemical action which the zinc and the acid exert on each other; they are accompanied by a change in form and structure, which both undergo.

The acid loses its chemical character; the zinc enters into combination with it. The manifestations of force produced in the wire are the immediate consequence of the change in the properties of the acid and the metal.

One particle of acid after another loses its peculiar chemical character; and we perceive that in the same proportion the wire acquires a chemical, mechanical, galvanic, or magnetic force, whatever name be given to it. According to the number of acid particles which in a given time undergo this change, that is, according to the surface of the zinc, the wire receives a greater or less amount of these forces.

The continuance of the current of force depends on the duration of the chemical action; and the duration of the latter is most closely connected with the carrying away, by conduction, of the force.

If we check the propagation of the current of force, the acid retains its chemical character. If we employ it to overcome chemical or mechanical resistance, to decompose chemical compounds, or to produce motion, the chemical action continues; that is to say, one particle of acid after another changes its properties.

In the preceding paragraphs we have considered these remarkable phenomena in a form which is independent of the explanations of the schools. Is the force which circulates in the wire the electrical force? Is it chemical affinity? Is it propagated in the conductor like a fluid set in motion, or in the form of a series of momenta of motion, like light and sound, from one particle of the conductor to another? All this we know not, and we shall never know. All the suppositions which may be employed as explanations of the phenomena have not the slightest influence on the truth of these phenomena; for they refer merely to the form in which they are manifested.

On some points, however, there is no doubt; namely, that all the effects which may be produced by the wire are determined by the change of properties in the zinc and in the acid; for the term " chemical action" signifies neither more nor less than the act of change in them; that these effects depend on the presence of a conductor, of a substance which propagates in all directions, where it is not neutralized by resistance, the force or momentum produced; that this force becomes a momentum of motion, by means of which we can produce mechanical effects, and which, when transferred to other bodies, communicates to them all those properties, the ultimate cause of which is the chemical force itself; for these bodies acquire the power of causing decompositions and combinations, such as, without a supply of force through the conductor, they could not effect.

If we employ these well known facts as means to assist us in investigating the ultimate cause of the mechanical effects in the animal organism, observation teaches us, that the motion of the blood and of the other animal fluids proceeds from distinct organs which, as in the case of the heart and intestines, do not generate the moving power in themselves, but receive it from other quarters.

We know with certainty that the nerves are the conductors and propagators of mechanical effects; we know, that by means of them motion is propagated in all directions. For each motion we recognize a separate nerve, a peculiar conductor, with the conducting power of which, or with its interruption, the propagation of motion is affected or destroyed.

By means of the nerves all parts of the body, all the limbs, receive the moving force which is indispensable to their functions, to change of place, to the production of mechanical effects. Where nerves are not found, motion does not occur. The excess of force generated in one place is conducted to other parts by the nerves. The force which one organ cannot produce in itself is conveyed to it from other quarters; and the vital force which is wanting to it, in order to furnish resistance to external causes of disturbance, it receives in the form of excess from another organ, an excess which that organ cannot consume in itself.

We observe further, that the voluntary and involuntary motions, in other words, all mechanical effects in the animal organism, are accompanied by, nay, are dependent on, a peculiar change of form and structure in the substance of certain living parts, the increase or diminution of which change stands in the very closest relation to the measure of motion, or the amount of force consumed in the motions performed.

As an immediate effect of the manifestation of mechanical force, we see, that a part of the muscular substance loses its vital properties, its character of life; that this portion separates from the living part, and loses its capacity of growth and its power of resistance. We find that this change of properties is accompanied by the entrance of a foreign body (oxygen) into the composition of the muscular fibre (just as the acid lost its chemical character by combining with zinc;) and all experience proves, that this conversion of living muscular fibre into compounds destitute of vitality is accelerated or retarded according to the amount of force employed to produce motion. Nay, it may safely be affirmed, that they are mutually proportional; that a rapid transformation of muscular fibre, or, as it may be called, a rapid change of matter, determines a greater amount of mechanical force; and conversely, that a greater amount of mechanical motion (of mechanical force expended in motion) determines a more rapid change of matter.

From this decided relation between the change of matter in the animal body and the force consumed in mechanical motion, no other conclusion can be drawn but this, that the active or available vital force in certain living parts is the cause of the mechanical phenomena in the animal organism.

The moving force certainly proceeds from living parts; these parts possessed a momentum of force or of motion, which they lost in proportion as other parts acquired a momentum of force or of motion; they lose their capacity of growth, and their power to resist external causes of change. It is obvious that the ultimate cause, the vital force, from which they acquired these properties, has served for the production of mechanical force, that is, has been expended in the shape of motion.

How, indeed, could we conceive that a living part should lose the condition of life, should become incapable of resisting the action of the oxygen conveyed to it by the arterial blood, and should be deprived of the power to overcome chemical resistance, unless the momentum of the vital force, which had given to it all these properties, had been expended for other purposes?

By the power of the conductors, the nerves to propagate the momentum of force in a living part, or the effect which the active vital force inherent in the part produces on all the surrounding parts, in all directions where the force, or rather its momentum of motion, is consumed without resistance, (for without motion no change of matter occurs, and when motion has begun, there is no longer resistance,) an equilibrium is obviously established in the living part, between the chemical forces and the remaining vital force; which equilibrium would not have occurred had not vital force been expended in producing mechanical motion.

In this state, any external cause capable of exerting an influence on the form, structure and composition of the organ meets with no further resistance. If oxygen were not conveyed to it, the organ would maintain its condition, but without any manifestation of vitality. It is only with the commencement of chemical action that the change of matter, that is, the separation of

a part of the organ in the form of lifeless compounds, begins.

The change of matter, the manfestation of mechanical force, and the absorption of oxygen, are, in the animal body, so closely connected with each other, that we may consider the amount of motion, and the quantity of living tissue transformed, as proportional to the quantity of oxygen inspired and consumed in a given time by the animal. For a certain amount of motion, for a certain proportion of vital force consumed as mechanical force, an equivalent of chemical force is manifested; that is, an equivalent of oxygen enters into combination with the substance of the organ which has lost the vital force; and a corresponding proportion of the substance of the organ is separated from the living tissue in the shape of an oxidized compound.

All those parts of the body which nature has destined to effect the change of matter, that is, to the production of mechanical force, are penetrated in all directions by a multitude of the most minute tubes or vessels, in which a current of oxygen continually circulates, in the form of arterial blood. To the above-mentioned separation of part of the elements of these parts, in other words, to the disturbance of their equilibrium, this oxygen is absolutely essential.

As long as the vital force of these parts is not conducted away and applied to other purposes, the oxygen of the arterial blood has not the slightest effect on the substance of the organized parts; and in all cases, only so much oxygen is taken up as corresponds to the conducting power, and, consequently to the mechanical effects produced.

The oxygen of the atmosphere is the proper, active, external cause of the waste of matter in the animal body; it acts like a force which disturbs and tends to destroy the manifestation of the vital force at every moment. But its effect as a chemical agent, the disturbance proceeding from it, is held in equilibrium by the vital force, which is free and available in the living tissue, or is annihilated by a chemical agency opposed to that of oxygen, the manifestation of which must be considered as dependent on the vital force.

In chemical language, to annihilate the chemical action of oxygen, means, to present to it substances, or parts of organs, which are capable of combining with it.

The action of oxygen (affinity) is either neutralized by means of the elements of organized parts, which combine with it, (after the free vital force has been conducted away,) or else the organ presents to it the products of other organs, or certain matters formed from the elements of the food, by the vital activity of certain systems of apparatus.

It is only the muscular system which, in this sense, produces in itself a resistance to the chemical action of oxygen, and neutralizes it completely.

The substance of cellular tissue, of membranes, and of the skin, the minutest particles of which are not in immediate contact with arterial blood, (with oxygen,) are not destined to undergo this change of matter. Whatever changes they may undergo in the vital process, affect, in all cases, only their surface.

The gelatinous tissues, mucous membranes, tendons, &c., are not designed to produce mechanical force; they contain in their substance no conductors of mechanical effects. But the muscular system is interwoven with innumerable nerves. The substance of the uterus is in no respect different in chemical composition from the other muscles; but it is not adapted to the change of matter, to the production of force, and contains no organs for conducting away the moving power. Cellular tissue, gelatinous membranes, and mucous membranes, are far from being destitute of the power of combining with oxygen, when moisture is present; we know that, when moist, they cannot be brought in contact with oxygen without undergoing a progressive alteration. But one surface of the intestines and the cells of the lungs are constantly in contact with oxygen; and it is obvious that they must be as rapidly altered by the chemical action of the oxygen in the body as out of it, were it not that there exists in the organism itself a source of resistance, which completely neutralizes the action of the oxygen. Among the means by which this resistance is furnished we may include all substances which are capable of combining with oxygen, or acquire that property under the influence of the vital force, and which surpass the tissues above mentioned in their power of neutralizing its chemical action.

All those constituents of the body which, in themselves, do not possess, in the form of vital force, the power of resisting the action of oxygen, must be far better adapted for the purpose of combining with, and neutralizing it, than those tissues which are under the influence of the vital force, although only through the nerves. In this point of view, we cannot fail to perceive the importance of the bile in regard to the substance of the intestines, and that of the pulmonary cells, as well as that of fat, of mucus, and of the secretions generally.

When the membranes are compelled from their own substance to furnish resistance to the action of the oxygen, that is, when there is a deficiency of the substances destined by nature for their protection, they must, since their renewal is confined within narrow limits, yield to the chemical action. The lungs and intestines will always simultaneously suffer abormal changes.

From the change of matter itself, from the metamorphosis of the living muscular tissue, these organs receive the means of resistance to the action of oxygen which are indispensable to their preservation. According to the rapidity of this process, the quantity of bile secreted increases; while that of the fat present in the body diminishes in the same proportion.

For carrying on the involuntary motions in the animal body, a certain amount of vital force is expended at every moment of its existence; and, consequently, an incessant change of matter goes on; but the amount of living tissue, which, in consequence of this form of consumption of vital force, loses its condition of life and its capacity of growth, is confined within narrow limits. It is directly proportional to the force required for these involuntary motions.

Now, although we may suppose that the living muscular tissue, with a sufficient supply of food, never loses its capacity of growth; that this form of vital manifestation is continually effective; this cannot apply to those parts of the body whose available vital force has been expended in producing mechanical effects. For the waste of matter, in consequence of motion and laborious exertion, is extremely various in different individuals.

If we reflect, that the slightest motion of a finger consumes force; that in consequence of the force expended, a corresponding portion of muscle diminishes in volume; it is obvious, that an *equilibrium between supply and waste of matter* (in living tissues) can only occur when the portion separated or expelled in a lifeless form is, at the same instant in which it loses its vital condition, restored in another part.

The capacity of growth or increase in mass depends on the momentum of force belonging to each part; and must be capable of continued manifestation (if there be a sufficient supply of nourishment,) as long as it does not lose this momentum, by expending it, for example, in producing motion.

In all circumstances, the growth itself is restricted to the time: that is to say, it cannot be unlimited in a limited time.

A living part cannot increase in volume at the same moment in which a portion of it loses the vital condition, and is expelled from the organ in the form of a lifeless compound; on the contrary, its volume must diminish.

The continued application of the momentum of force in living tissues to mechanical effects determines, therefore, a continued separation of matter; and only from the period at which the cause of waste ceases to operate, can the capacity of growth be manifested.

Now, since, in different individuals, according to the amount of force consumed in producing voluntary mechanical effects, unequal quantities of living tissue are wasted, there must occur, in every individual, unless the phenomena of motion are to cease entirely, a condition in which all voluntary motions are completely checked, in which, therefore, these occasion no waste. This condition is called *sleep*.

The growth of one part, which is not deprived of its vital force, cannot be in the slightest degree affected by the consumption of the vital force of another part in producing motion. The one may increase in volume, while the other diminishes; and the waste in one can neither increase nor diminish the supply in the other.

Now, since the consumption of force for the involuntary motions continues in sleep, it is plain that a waste of matter also continues in that state; and if the original equilibrium is to be restored, we must suppose that, during sleep, an amount of force is accumulated in the form of living tissue, exactly equal to that which was consumed in voluntary and involuntary motion during the preceding waking period.

If the equilibrium between waste and supply of matter be in the least degree disturbed, this is instantly seen in the different amount of force available for mechanical purposes.

It is further obvious, that if there should occur a disproportion between the conducting power of the nerves of voluntary and involuntary motion, a difference in the phenomena of motion themselves will be perceptible, in the same proportion as the one or the other is capable of propagating the momentum of force, generated by the change of matter. As the motions of the circulating system and of the intestines increase, the power of producing mechanical effects in the limbs must diminish in the same proportion (as in wasting fevers;) and if, in a given time, more vital force has been consumed for mechanical purposes (labour, running, dancing, &c.,) than is properly available for the voluntary and involuntary motions; if force be expended more rapidly than the change of matter can be effected in the same time; then a part of that force which is necessary for the involuntary motions must be expended in restoring the excess of force consumed in voluntary motion. The motions of the heart and of the intestines, in this case, will be retarded, or will entirely cease.

From the unequal degree of conducting power in the nerves, we must deduce those conditions which are termed paralysis, syncope, and spasm. Paralysis of the nerves of voluntary motion may exist without emaciation; but frequently recurring attacks of epilepsy (in which vital force is rapidly wasted in producing mechanical effects) are always accompanied by remarkably rapid emaciation.

It ought to excite the highest admiration when we consider with what infinite wisdom the Creator has divided the means by which animals and plants are qualified for their functions, for their peculiar vital manifestations.

The living part of a plant requires the whole force and direction of its vital energy from the absence of all conductors of force. By this means the leaf is enabled to overcome the strongest chemical attractions, to decompose carbonic acid, and to assimilate the elements of its nourishment.

In the flower alone does a process similar to the change of matter in the animal body occur. There, phenomena of motion appear; but the mechanical effects are not propagated to a distance, owing to the absence of conductors of force.

The same vital force which we recognize in the plant as an almost unlimited capacity of growth, is converted in the animal body into moving power (into a current of vital force;) and a most wonderful and wise economy has destined for the nourishment of the animal only such compounds as have a composition identical with that of the organs which generate force, that is, with the muscular tissue. The expenditure of force which the living parts of animals require, in order to reproduce themselves from the blood; the resistance of the chemical force which has to be overcome in the azotized constituents of food by the vital agency of the organs destined to convert them into blood; these are as nothing compared to the force with which the elements of carbonic acid are held together. A certain amount of force would necessarily be prevented from assuming the form of moving power, if it were to be expended in overcoming chemical resistance; for the momentum of motion of the vital force is diminished by all obstacles. But the conversion of the constituents of blood into muscular fibre (into an organ which generates force) is only a change of form. Both have the same composition; blood is fluid, muscular fibre is solid blood. We may even suppose that this change takes place without any expenditure of vital force; for the mere passage of a fluid body into the solid state requires no manifestation of force, but only the removal of obstacles, which oppose that force (cohesion) which determines the form of matter, in its manifestations.

In what form or in what manner the vital force produces mechanical effects in the animal body is altogether unknown, and is as little to be ascertained by experiment as the connexion of chemical action with the phenomena of motion which we can produce with the galvanic battery. All the explanations which have been attempted are only representations of the phenomenon; they are, more or less, exact descriptions and comparisons of known phenomena with these, whose cause is unknown. In this respect we are like an ignorant man, to whom the rise and fall of an iron rod in a cylinder, in which the eye can perceive nothing, and its connexion with the turning and motion of a thousand wheels at a distance from the piston-rod, appear incomprehensible.

We know not how a certain something, invisible and imponderable in itself (heat) gives to certain bodies the power of exerting an enormous pressure on surrounding objects; we know not even how this something itself is produced when we burn wood or coals.

So is it with the vital force, and with the phenomena exhibited by living bodies. The cause of these phenomena is not chemical force; it is not electricity, nor magnetism; it is a force which has certain properties in common with all causes of motion and of change in form and structure in material substances. It is a peculiar force, because it exhibits manifestations which are found in no other known force.

II. In the living plant, the intensity of the vital force far exceeds that of the chemical action of oxygen.

We know, with the utmost certainty, that by the influence of the vital force, oxygen is separated from elements to which it has the strongest affinity; that it is given out in the gaseous form, without exerting the slightest action on the juices of the plant.

How powerful, indeed, must the resistance appear which the vital force supplies to leaves charged with oil of turpentine or tannic acid, when we consider the affinity of oxygen for these compounds!

This intensity of action or of resistance the plant obtains by means of the sun's light; the effect of which in chemical actions may be, and is, compared to that of a very high temperature (moderate red heat.)

During the night an opposite process goes on in the plant; we see then that the constituents of the leaves and green parts combine with the oxygen of the air, a property which in daylight they did not possess.

From these facts we can draw no other conclusion but this: that the intensity of the vital force diminishes with the abstraction of light; that with the approach of night a state of equilibrium is established, and that in complete darkness all those constituents of plants which, during the day, possessed the power of separating oxygen from chemical combinations, and of resisting its action, lose their power completely.

A precisely similar phenomenon is observed in animals.

The living animal body exhibits its peculiar manifestations of vitality only at certain temperatures. When exposed to a certain degree of cold, these vital phenomena entirely cease.

The abstraction of heat must, therefore, be viewed as quite equivalent to a diminution of the vital energy; the resistance opposed by the vital force to external causes of disturbance must diminish, in certain temperatures, in the same ratio in which the tendency of the elements of the body to combine with the oxygen of the air increases.

By the combination of oxygen with the constituents of the metamorphosed tissues, the temperature necessary to the manifestations of vitality is produced in the carnivora. In the herbivora, again, a certain amount of heat is developed by means of those elements of their non-azotized food which have the property of combining with oxygen.

It is obvious that the temperature of an animal body cannot change, if the amount of inspired oxygen increases in the same ratio as the loss of heat by external cooling.

Two individuals, carnivora, of equal weight, exposed to unequal degrees of cold, lose, in a given time, by external cooling, unequal quantities of heat. Experience teaches, that if their peculiar temperature and their original weight are to remain unaltered, they require unequal quantities of food; more in the lower temperature than in the higher.

The circumstance that the original weight remains the same, with unequal quantities of food, obviously presupposes, that in the same time a quantity of oxygen proportioned to the temperature has been absorbed; more in the lower than in the higher temperature.

We find that the weight of both individuals, at the end of 24 hours, is equal to the original weight. But we have assumed that their food is converted into blood; that the blood has served for nutrition; and it is plain, that when the original weight has been restored, a quantity of the constituents of the body, equal in weight to those of the food, has lost its condition of life, and has been expelled in combination with oxygen.

The one individual, which, being exposed to the lower temperature, consumed more food, has also absorbed more oxygen; a greater quantity of the constituents of its body has been separated in combination with oxygen; and, in consequence of this combination with oxygen, a greater amount of heat has been liberated, by which means the heat abstracted has been restored, and the proper temperature of the body kept up.

Consequently, by the abstraction of heat, provided there be a full supply of food and free access of oxygen, the change of matter must be accelerated; and, along with the augmented transformation, in a given time, of living tissues, a greater amount of vital force must be rendered available for mechanical purposes.

With the external cooling, the respiratory motions become stronger; in a lower temperature more oxygen is conveyed to the blood; the waste of matter increases, and if the supply be not kept in equilibrium with this waste, by means of food, the temperature of the body gradually sinks.

But, in a given time, an unlimited supply of oxygen cannot be introduced into the body; only a certain amount of living tissue can lose the state of life, and only a limited amount of vital force can be manifested in mechanical phenomena. It is only, therefore, when the cooling, the generation of force, and the absorption of oxygen are in equilibrium together, that the temperature of the body can remain unchanged. If the loss of heat by cooling go beyond a certain point, the vital phenomena diminish in the same ratio; for the temperature falls, and the temperature must be considered as a uniform condition of their manifestation.

Now experience teaches, that when the temperature of the body sinks, the power of the limbs to produce mechanical effects (or the force necessary to the voluntary motions) is also diminished. The condition of sleep ensues, and at last even the involuntary motions (those of the heart and intestines, for example) cease, and apparent death or syncope supervenes.

It is obvious that the cause of the generation of force, namely, the change of matter, is diminished, because, with the abstraction of heat, as in the plant by abstraction of light, the intensity of the vital force diminishes. It is also obvious that the momentum of force in a living part depends on its proper temperature; exactly as the effect of a falling body stands in a fixed relation to certain other conditions; for example, to the velocity attained in falling.

When the temperature sinks, the vital energy diminishes; when it again rises, the momentum of force in the living parts appears once more in all its original intensity.

The production of force for mechanical purposes, and the temperature of the body, must, consequently, bear a fixed relation to the amount of oxygen which can be absorbed in a given time by the animal body.

The quantities of oxygen which a whale and a carrier's horse can inspire in a given time are very unequal. The temperature, as well as the quantity of oxygen, is much greater in the horse.

The force exerted by a whale, when struck with the harpoon, his body being supported by the surrounding medium, and the force exerted by a carrier's horse, which carries its own weight and a heavy burden for eight or ten hours, must both bear the same ratio to the oxygen consumed. If we take into consideration the time during which the force is manifested, it is obvious that the amount of force developed by the horse is far greater than in the case of the whale.

In climbing high mountains, where, in consequence of the respiration of a highly rarefied atmosphere, much less oxygen is conveyed to the blood, in equal times, than in valleys or at the level of the sea, the change of matter diminishes in the same ratio, and with it the amount of force available for mechanical purposes. For the most part, drowsiness and want of force for mechanical exertions come on; after twenty or thirty steps, fatigue compels us to a fresh accumulation of force by means of rest (absorption of oxygen without waste of force in voluntary motions.)

By the absorption of oxygen into the substance of living tissues, these lose their condition of life, and are separated as lifeless, unorganized compounds; but the whole of the inspired oxygen is not applied to these transformations: the greater part serves to convert into gas and vapour all matters which no longer belong to the organism; and, as formerly mentioned, the combination of the elements of such compounds

with the oxygen produces the temperature proper to the animal organism.

The production of heat and the change of matter are closely related to each other: but although heat can be produced in the body without any change of matter in living tissues, yet the change of matter cannot be supposed to take place without the co-operation of oxygen.

According to all the observations hitherto made, neither the expired air nor the perspiration, nor the urine, contains any trace of alcohol, after indulgence in spirituous liquors; and there can be no doubt that the elements of alcohol combine with oxygen in the body; that its carbon and hydrogen are given off as carbonic acid and water.

The oxygen which has accomplished this change must have been taken from the arterial blood; for we know of no channel, save the circulation of the blood, by which oxygen can penetrate into the interior of the body.

Owing to its volatility, and the ease with which its vapour permeates animal membranes and tissues, alcohol can spread throughout the body in all directions.

If the power of the elements of alcohol to combine with oxygen were not greater than that of the compounds formed by the change of matter, or that of the substance of living tissues, they (the elements of alcohol) could not combine with oxygen in the body.

It is, consequently, obvious, that by the use of alcohol a limit must rapidly be put to the change of matter in certain parts of the body. The oxygen of the arterial blood, which, in the absence of alcohol, would have combined with the matter of the tissues, or with that formed by the metamorphosis of these tissues, now combines with the elements of alcohol. The arterial blood becomes venous, without the substance of the muscles having taken any share in the transformation.

Now we observe, that the developement of heat in the body, after the use of wine, increases rather than diminishes, without the manifestation of a corresponding amount of mechanical force.

A moderate quantity of wine, in women and children unaccustomed to its use, produces, on the contrary, a diminution of the force necessary for voluntary motions. Weariness, feebleness in the limbs, and drowsiness, plainly show that the force available for mechanical purposes, in other words, the change of matter, has been diminished.

A diminution of the conducting power of the nerves of voluntary motion may doubtless take a certain share in producing these symptoms; but this must be altogether without influence on the sum of available force.

What the conductors of voluntary motion cannot carry away for effects of force, must be taken up by the nerves of involuntary motion, and conveyed to the heart, lungs, and intestines. In this case, the circulation will appear accelerated at the expense of the force available for voluntary motion; but, as was before remarked, without the production of a greater amount of mechanical force by the process of oxidation of the alcohol.

Finally, we observe, in hybernating animals, that, during their winter sleep, the capacity of increase in mass (one of the chief manifestations of the vital force,) owing to the absence of food, is entirely suppressed. In several, apparent death occurs in consequence of the low temperature and of the diminution of vital energy thus produced; in others, the involuntary motions continue, and the animal preserves a temperature independent of the surrounding temperature. The respirations go on; oxygen, the condition which determines the production of heat and force, is absorbed now as well as in the former state of the animal; and previous to the winter sleep, we find all those parts of their body, which in themselves are unable to furnish resistance to the action of the oxygen, and which, like the intestines and membranes, are not destined for the change of matter, covered with fat; that is, surrounded by a substance which supplies the want of resistance.

If we now suppose, that the oxygen absorbed during the winter sleep combines, not with the elements of living tissues, but with those of the fat, then the living part, although a certain momentum of motion be expended in keeping up the circulation, will not be separated and expelled from the body.

With the return of the higher temperature, the capacity of growth increases in the same ratio, and the motion of the blood increases with the absorption of oxygen. Many of these animals become emaciated during the winter sleep, others not till after awaking from it.

In hybernating animals the active force of the living parts is exclusively devoted, during hybernation, to the support of the involuntary motions. The expenditure of force in voluntary motion is entirely suppressed.

In contradistinction to these phenomena, we know that, in the case of excess of motion and exertion, the active force in living parts may be exclusively and entirely consumed in producing voluntary mechanical effects; in such wise that no force shall remain available for the involuntary motions. A stag may be hunted to death; but this cannot occur without the metamorphosis of all the living parts of its muscular system, and its flesh becomes uneatable. The condition of metamorphosis into which it has been brought by an enormous consumption both of force and of oxygen continues when all phenomena of motion have ceased. In the living tissues, all the resistance offered by the vital force to external agencies of change is entirely destroyed.

But however closely the conditions of the production of heat and of force may seem to be connected together, with reference to mechanical effects, yet the disengagement of heat can in no way be considered as in itself the only cause of these effects.

All experience proves, that there is, in the organism, only one source of mechanical power; and this source is the conversion of living parts into lifeless, amorphous compounds.

Proceeding from this truth, which is independent of all theory, animal life may be viewed as determined by the mutual action of opposed forces; of which one class must be considered as *causes of increase,* (of supply of matter,) and the other as *causes of diminution* (of waste of matter.)

The increase of mass is effected in living parts by the vital force; the manifestation of this power is dependent on heat; that is, on a certain temperature peculiar to each specific organism.

The cause of waste of matter is the chemical action of oxygen; and its manifestation is dependent on the abstraction of heat as well as on the expenditure of the vital force for mechanical purposes.

The act of waste of matter is called the change of matter; it occurs in consequence of the absorption of oxygen into the substance of living parts. This absorption of oxygen occurs only when the resistance which the vital force of the living parts opposes to the chemical action of the oxygen is weaker than that chemical action; and this weaker resistance is determined by the abstraction of heat, or by the expenditure in mechanical motions of the available force of living parts.

By the combination of the oxygen introduced into the arterial blood with such constituents of the body as offer no resistance to its action, the temperature necessary for the manifestation of vital activity is produced.

From the relations between the consumption of oxygen on the one hand and the change of matter and developement of heat on the other, the following general rules may be deduced.

For every proportion of oxygen which enters into combination in the body, a corresponding proportion of heat must be generated.

The sum of force available for mechanical purposes must be equal to the sum of vital forces of all tissues adapted to the change of matter.

If, in equal times, unequal quantities of oxygen are consumed, the result is obvious, in an unequal amount of heat liberated, and of mechanical force.

When unequal amounts of mechanical force are expended, this determines the absorption of corresponding and unequal quantities of oxygen.

For the conversion of living tissues into lifeless compounds, and for the combination of oxygen with such constituents of the body as have an affinity for it, *time is required.*

In a given time, only a limited amount of mechanical force can be manifested, and only a limited amount of heat can be liberated.

That which is expended, in mechanical effects, in the shape of velocity, is lost in time; that is to say, the more rapid the motions are, the sooner or the more quickly is the force exhausted.

The sum of the mechanical force produced in a given time is equal to the sum of force necessary, during the same time, to produce the voluntary and involuntary motions; that is, all the force which the heart, intestines, &c., require for their motions is lost to the voluntary motions.

The amount of azotized food necessary to restore the equilibrium between waste and supply is directly proportional to the amount of tissues metamorphosed.

The amount of living matter, which in the body loses the condition of life, is, in equal temperatures, directly proportional to the mechanical effects produced in a given time.

The amount of tissue metamorphosed in a given time may be measured by the quantity of nitrogen in the urine.

The sum of the mechanical effects produced in two individuals, in the same temperature, is proportional to the amount of nitrogen in their urine; whether the mechanical force has been employed in voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera.

That condition of the body which is called ***health*** includes the conception of an equilibrium among all the causes of waste and of supply; and thus animal life is recognized as the mutual action of both; and appears as an alternating destruction and restoration of the state of equilibrium.

In regard to its absolute amount, the waste and supply of matter is, in the different periods of life, unequal; but, in the state of health, the available vital force must always be considered as a constant quantity, corresponding to the sum of living particles.

Growth, or the increase of mass, stands, at every age, in a fixed relation to the amount of vital force consumed as moving power.

The vital force, which is expended for mechanical purposes, is subtracted from the sum of the force available for the purpose of increase of mass.

The active force, which is consumed in the body in overcoming resistance (in causing increase of mass) cannot, at the same time, be employed to produce mechanical effects.

Hence it follows necessarily, that when, as in childhood, the supply exceeds the waste of matter, the mechanical effects produced must be less in the same proportion.

With the increase of mechanical effects

produced, the capacity of increase of mass or of the supply of waste in living tissues must diminish in the same proportion.

A perfect balance between the consumption of vital force for supply of matter and that for mechanical effects occurs, therefore, only in the adult state. It is at once recognized in the complete supply of the matter consumed. In old age more is wasted; in childhood more is supplied than wasted.

The force available for mechanical purposes in an adult man is reckoned, in mechanics, equal to the $\frac{1}{5}$th of his own weight, which he can move during eight hours, with a velocity of five feet in two seconds.

If the weight of a man be 150 lbs., his force is equal to a weight of 30 lbs. carried by him to a distance of 72,000 feet. For every second his momentum of force is $= 30 \times 2{\cdot}5 = 75$ lbs.; and for the whole day's work his momentum of motion is $= 30 \times 72{,}000 = 216{,}000$.

By the restoration of the original weight of his body, the man collects again a sum of force which allows him, next day, to produce, without exhaustion, the same amount of mechanical effects.

This supply of force is furnished in a seven hours' sleep.

In manufactories of rolled iron it frequently happens, that the pressure of the engine, going at its ordinary rate, is not sufficient to force a rod of iron of a certain thickness to pass below the cylinders. The workman, in this case, allows the whole force of the steam to act on the revolving wheel, and not until this has acquired a great velocity does he bring the rod under the rollers; when it is instantly flattened with great ease into a plate, while the wheel gradually loses the velocity it had acquired. What the wheel gained in velocity the roller gained in force; by this process force was obviously collected, accumulated in the velocity; but in this sense force does not accumulate in the living organism.

The restoration of force is effected, in the animal body, by the transformation of the separated parts, destined for the production of force, and by the expenditure of the active vital force in causing *formation of new parts;* and, with the restoration of the separated or effete parts, the organism recovers a force equal to that which has been expended.

It is plain, that the vital force manifested, during sleep, in the formation of new parts, must be equal to the whole sum of the moving power expended in the waking state in all mechanical effects whatever, *plus* a certain amount of force, which is required for carrying on those involuntary motions which continue during sleep.

From day to day, the labouring man, with sufficient food, recovers, in seven hours' sleep, the whole sum of force; and without reckoning the force necessary for the involuntary motions which may be considered equal in all men, we may assume, that the mechanical force available for work is directly proportional to the number of hours of sleep.

The adult man sleeps 7 hours, and wakes 17 hours; consequently, *if the equilibrium be restored* in 24 hours, the mechanical effects produced in 17 hours must be equal to the effects produced during 7 hours in the shape of formation of new parts.

An old man sleeps only 3½ hours; and if every thing else be supposed the same as in the case of the adult, he will be able, at all events, to produce half of the mechanical effects produced by an adult of equal weight; that is, he will be able to carry only 15 lbs. instead of 30 to the same distance.

The infant at the breast sleeps 20 hours and wakes only four; the active force consumed in formation of new parts is, in this case, to that consumed in mechanical effects (in motion of the limbs) as 20 to 4; but his limbs possess no momentum of force, for he cannot yet support his own body. If we assume, that the aged man and infant consume in mechanical effects a quantity of force corresponding to the proportion available in the adult, then the mechanical effects are proportional to the number of waking hours, the formation of new parts to the number of hours of sleep, and we shall have:

	Force expended in mechanical effects.		*Force expended in formation of new parts.*
In the adult . .	17	:	7
In the infant . .	4	:	20
In the old man .	20	:	4

In the adult a perfect equilibrium takes place between waste and supply; in the old man and in the infant, waste and supply are not in equilibrium. If we make the consumption of force in the 17 waking hours equal to that required for the restoration of the equilibrium during sleep $= 100 = 17$ waking hours, $= 7$ hours of sleep, we obtain the following proportions. The mechanical effects are to those in the shape of formation of new parts:

In the adult man = 100 : 100
In the infant . . = 25 : 250
In the old man . = 125 : 50

Or the increase of mass to the diminution by waste:

In the adult man = 100 : 100
In the infant . . = 100 : 10
In the old man . = 100 : 250

It is consequently clear, that if the old man performs an amount of work proportional to the sleeping hours of the adult, the waste will be greater than the supply; that is, his body will rapidly decrease in weight, if he carry 15 lbs. to the distance of 72,000 feet with a velocity of 2½ feet in the second; but he will be able, without injury, to carry 6 lbs. to the same distance.

In the infant the increase is to the decrease as 10 to 1, and consequently, if we in his case increase the expenditure of force in mechanical effects to ten times its proper amount, there will thus be established only an equilibrium between waste and supply

The child, indeed, will not grow, but neither will it lose weight.

If, in the adult man, the consumption of force for mechanical purposes in 24 hours be augmented beyond the amount restorable in seven hours of sleep, then, if the equilibrium is to be restored, less force, in the same proportion, must be expended in mechanical effects in the next 24 hours. If this be not done, the mass of the body decreases, and the state characteristic of old age more or less decidedly supervenes.

With every hour of sleep the sum of available force increases in the old man, or approaches the state of equilibrium between waste and supply which exists in the adult.

It is further evident, that if a part of the force which is available for mechanical purposes, without disturbing the equilibrium, should not be consumed in moving the limbs, in raising weights, or in other labour, it will be available for involuntary motions. If the motion of the heart, of the fluids, and of the intestines (the circulation of the blood and digestion) are accelerated in proportion to the amount of force not consumed in voluntary motions, the weight of the body will neither increase or diminish in 24 hours. The body, therefore, can only increase in mass, if the force accumulated during sleep, and available for mechanical purposes, is employed neither for voluntary nor for involuntary motions.

The numerical values above given for the expenditure of force in the human body refer, as has been expressly stated, only to a given, uniform temperature. In a different temperature, and with deficient nourishment, all these proportions must be changed.

If we surround a part of the body with ice or snow, while other parts are left in the natural state, there occurs, more or less quickly, in consequence of the loss of heat, an accelerated change of matter in the cooled part.

The resistance of the living tissues to the action of oxygen is weaker at the cooled part than in the other parts; and this, in its effects, is equivalent to an increase of resistance in these other parts.

The momentum of force of the vitality in the parts which are not cooled is expended, as before, in mechanical motion; but the whole action of the inspired oxygen is exerted on the cooled part.

If we imagine an iron cylinder, into which we admit steam under a certain pressure, then if the force with which the particles of the iron cohere be equal to the force which tends to separate them, an equilibrium will result; that is, the whole effect of the steam will be neutralized by the resistance. But if one of the sides of the cylinder be moveable, a piston-rod, for example, and offer to the pressure of the steam a less resistance than other parts, the whole force will be expended in moving this one side—that is, in raising the piston-rod. If we do not introduce fresh steam (fresh force) an equilibrium will soon be established. The piston-rod resists a certain force without moving, but is raised by an increased pressure. When this excess of force has been consumed in motion, it cannot be raised higher; but if new vapour be continually admitted, the rod will continue to move.

In the cooled part of the body, the living tissues offer a less resistance to the chemical action of the inspired oxygen; the power of the oxygen to unite with the elements of the tissues is, at this part, exalted. When the part has once lost its condition of life, resistance entirely ceases; and in consequence of the combination of the oxygen with the elements of the metamorphosed tissues, a greater amount of heat is liberated.

For a given amount of oxygen, the heat produced is, in all cases, exactly the same. In the cooled part, the change of matter, and with it the disengagement of heat, increases; while in the other parts the change of matter and liberation of heat decrease. But when the cooled part, by the union of oxygen with the elements of the metamorphosed tissues, has recovered its original temperature, the resistance of its living particles to the oxygen conveyed to them again increases, and, as the resistance of other parts is now diminished, a more rapid change of matter now occurs in them, their temperature rises, and along with this, if the cause of the change of matter continues to operate, a larger amount of vital force becomes available for mechanical purposes.

Let us now suppose that heat is abstracted from the whole surface of the body; in this case the whole action of the oxygen will be directed to the skin, and in a short time the change of matter must increase throughout the body. Fat, and all such matters as are capable of combining with the oxygen which is brought to them in larger quantity than usual, will be expelled from the body in the form of oxidized compounds.

III.—THEORY OF DISEASE. Every substance or matter, every chemical or mechanical agency, which changes or disturbs the restoration of the equilibrium between the manifestations of the causes of waste and supply, in such a way as to add its action to the causes of waste, is called *a cause of disease*. *Disease* occurs when the sum of vital force, which tends to neutralize all causes of disturbance, (in other words, when the resistance offered by the vital force,) is weaker than the acting cause of disturbance.

Death is that condition in which all resistance on the part of the vital force entirely ceases. So long as this condition is not established, the living tissues continue to offer resistance.

To the observer, the action of a cause of disease exhibits itself in the disturbance of the proportion between waste and supply which is proper to each period of life. In medicine, every abnormal condition of supply or of waste, in all parts or in a single part of the body, is called disease.

It is evident that one and the same cause of disease will produce in the organism very different effects, according to the period of life; and that a certain amount of disturbance, which produces disease in the adult state, may be without influence in childhood or in old age. A cause of disease may, when it is added to the cause of waste in old age, produce death (annihilate all resistance on the part of the vital force;) while in the adult state it may produce only a disproportion between supply and waste; and in infancy, only an equilibrium between supply and waste (the abstract state of health.)

A cause of disease which strengthens the causes of supply, either directly or indirectly by weakening the action of the causes of waste, destroys, in the child and in the adult, the relative normal state of health; while in old age it merely brings the waste and supply into equilibrium.

A child, lightly clothed, can bear cooling by a low external temperature without injury to health; the force available for mechanical purposes and the temperature of its body increases with the change of matter which follows the cooling; while a higher temperature, which impedes the change of matter, is followed by disease.

On the other hand, we see, in hospitals and charitable institutions (in Brussels, for example) in which old people spend the last years of life, when the temperature of the dormitory in winter sinks 2 or 3 degrees below the usual point, that by this slight degree of cooling the death of the oldest and weakest males as well as females is brought about. They are found lying tranquilly in bed, without the slightest symptoms of disease, or of the usual recognizable causes of death.

A deficiency of resistance, in a living part, to the cause of waste is, obviously, a deficiency of resistance to the action of the oxygen of the atmosphere.

When, from any cause whatever, this resistance diminishes in a living part, the change of matter increases in an equal degree.

Now, since the phenomena of motion in the animal body are dependent on the change of matter, the increase of the change of matter in any part is followed by an increase of all motions. According to the conducting power of the nerves, the available force is carried away by the nerves of involuntary motion alone, or by all the nerves together.

Consequently, if, in consequence of a diseased transformation of living tissues, a greater amount of force be generated than is required for the production of the normal motions, it is seen in an acceleration of all or some of the involuntary motions, as well as in a higher temperature of the diseased part.

This condition is called *fever*.

When a great excess of force is produced by change of matter, the force, since it can only be consumed by motion, extends itself to the apparatus of voluntary motion.

This state is called *a febrile paroxysm*.

In consequence of the acceleration of the circulation in the state of fever, a greater amount of arterial blood, and, consequently of oxygen, is conveyed to the diseased part, as well as to all other parts; and if the active force in the healthy parts continue uniform, the whole action of the excess of oxygen must be exerted on the diseased part alone.

According as a single organ, or a system of organs, is affected, the change of matter extends to one part alone, or to the whole affected system.

Should there be formed, in the diseased parts, in consequence of the change of matter, from the elements of the blood or of the tissue, new products, which the neighbouring parts cannot employ for their own vital functions;—should the surrounding parts, moreover, be unable to convey these products to other parts, where they may undergo transformation, then these new products will suffer, at the place where they have been formed, a process of decomposition analogous to fermentation or putrefaction.

In certain cases, medicine removes these diseased conditions, by exciting in the vicinity of the diseased part, or in any convenient situation, an artificial diseased state (as by blisters, sinapisms, or setons); thus diminishing, by means of artificial disturbance, the resistance offered to the external causes of change in these parts by the vital force. The physician succeeds in putting an end to the original diseased condition, when the disturbance artificially excited (or the diminution of resistance in another part) exceeds in amount the diseased state to be overcome.

The accelerated change of matter and the elevated temperature in the diseased part show, that the resistance offered by the vital force to the action of oxygen is feebler than in the healthy state. But this resistance only ceases entirely when death takes place. By the artificial diminution of resistance in another part, the resistance in the diseased organ is not indeed directly strengthened; but the chemical action (the cause of the change of matter) is diminished in the diseased part, being directed to another part, where the physician has succeeded in producing a still more feeble resistance to the change of matter (to the action of oxygen).

A complete cure of the original disease occurs, when external action and resistance, in the diseased part, are brought into equilibrium. Health and the restoration of the diseased tissue to its original condition follow, when we are able so far to weaken the disturbing action of oxygen, by any means, that it becomes inferior to the resistance offered by the vital force, which, although enfeebled, has never ceased to act; for this proportion between these causes of change is the uniform and necessary condition of increase of mass in the living organism.

In cases of a different kind, where artificial external disturbance produces no effect, the physician adopts other indirect methods to exalt the resistance offered by the vital force. These methods, the result of ages of experience, are such, that the most perfect theory could hardly have pointed them out more acutely or more justly than has been done by the observation of sagacious practitioners. He diminishes, by blood-letting, the number of the carriers of oxygen, (the globules,) and by this means the conditions of change of matter; he excludes from the food all such matters as are capable of conversion into blood; he gives chiefly or entirely non-azotized food, which supports the respiratory process, as well as fruit and vegetables, which contain the alkalies necessary for the secretions.

If he succeed, by these means, in diminishing the action of the oxygen in the blood on the diseased part, so far that the vital force of the latter, its resistance, in the smallest degree overcomes the chemical action; and if he accomplish this, without arresting the functions of the other organs, then restoration to health is certain.

To the method of cure adopted in such cases, if employed with sagacity and acute observation, there is added, as we may call it, an ally on the side of the diseased organ, and this is the vital force of the healthy parts. For, when blood is abstracted, the external causes of change are diminished also in them, and their vital force, formerly neutralized by these causes, now obtains the preponderance. The change of matter, indeed, is diminished throughout the body, and with it the phenomena of motion: but the sum of all resisting powers, taken together, increases in proportion as the amount of the oxygen acting on them in the blood is diminished. In the sensation of *hunger*, this resistance, in a certain sense, makes itself known; and the preponderating vital force exhibits itself, in many patients, when hunger is felt, in the form of an abnormal growth, or in abnormal metamorphosis of certain parts of organs. *Sympathy* is the transference of diminished resistance from one part, not exactly to the next, but to more distant organs, when the functions of both mutually influence each other. When the action of the diseased organ is connected with that of another—when, for example, the one no longer produces the matters necessary to the performance of the functions of the other—then the diseased condition is transferred, but only apparently, to the latter.

In regard to the nature and essence of the vital force, we can hardly deceive ourselves, when we reflect, that it behaves, in all its manifestations, exactly like other natural forces; that it is devoid of consciousness or of volition, and is subject to the action of a blister.

The nerves, which accomplish the voluntary and involuntary motions in the body, are, according to the preceding exposition, not the producers, but only the conductors of the vital force; they propagate motion, and behave towards other causes of motion, which in their manifestations are analogous to the vital force, towards a current of electricity, for example, in a precisely analogous manner. They permit the current to traverse them, and present, as conductors of electricity, all the phenomena which they exhibit as conductors of the vital force. In the present state of our knowledge, no one, probably, will imagine that electricity is to be considered as the cause of the phenomena of motion in the body; but still, the medicinal action of electricity, as well as that of a magnet, which, when placed in contact with the body, produces a current of electricity, cannot be denied. For to the existing force of motion or of disturbance there is added, in the electrical current, a new cause of motion and of change in form and structure, which cannot be considered as altogether inefficient.

Practical medicine, in many diseases, makes use of cold in a highly rational manner, as a means of exalting and accelerating, in an unwonted degree, the change of matter. This occurs especially in certain morbid conditions in the substance of the centre of the apparatus of motion; when a glowing heat and a rapid current of blood towards the head point out an abnormal metamorphosis of the brain. When this condition continues beyond a certain time, experience teaches that all motions in the body cease. If the change of matter be chiefly confined to the brain, then the change of matter, the generation of force, diminishes in all other parts. By surrounding the head with ice, the temperature is lowered, but the cause of the liberation of heat continues; the metamorphosis, which decides the issue of the disease, is limited to a short period. We must not forget, that the ice melts and absorbs heat from the diseased part; that if the ice be removed before the completion of the metamorphosis, the temperature again rises; that far more heat is removed by means of ice than if we were to surround the head with a bad conductor of heat. There has obviously been liberated in an equal time a far larger amount of heat than in the state of health; and this is only rendered possible by an increased supply of oxygen, which must have determined a more rapid change of matter.

The self-regulating steam engines, in which, to produce a uniform motion, the human intellect has shown the most admirable acuteness and sagacity, furnish no unapt image of what occurs in the animal body.

Every one knows, that in the tube which conveys the steam to the cylinder where the piston-rod is to be raised, a stop-cock of peculiar construction is placed, through which all the steam must pass. By an arrangement connected with the regulating

wheel, this stop-cock opens when the wheel moves slower, and closes more or less completely when the wheel moves faster than is required for a uniform motion. When it opens, more steam is admitted, (more force,) and the motion of the machine is accelerated. When it shuts, the steam is more or less cut off, the force acting on the piston-rod diminishes, the tension of the steam increases, and this tension is accumulated for subsequent use. The tension of the vapour, or the force, so to speak, is produced by change of matter, by the combustion of coals in the fire-place. The force increases (the amount of steam generated and its tension increase) with the temperature in the fire-place, which depends on the supply of coals and of air. There are in these engines other arrangements, all intended for regulation. When the tension of steam in the boiler rises beyond a certain point, the passages for admission of air close themselves; the combustion is retarded, the supply of force (of steam) is diminished. When the engine goes slower, more steam is admitted to the cylinder, its tension diminishes, the air passages are opened, and the cause of disengagement of heat (or production of force) increases. Another arrangement supplies the fire-place incessantly with coals in proportion as they are wanted.

If we now lower the temperature at any part of the boiler, the tension within is diminished; this is immediately seen in the regulators of force, which act precisely as if we had removed from the boiler a certain quantity of steam (force.) The regulator and the air-passages open, and the machine supplies itself with more coals.

The body, in regard to the production of heat and of force, acts just like one of these machines. With the lowering of the external temperature, the respirations become deeper and more frequent; oxygen is supplied in greater quantity and of greater density; the change of matter is increased, and more food must be supplied, if the temperature of the body is to remain unchanged.

It is hardly necessary to mention, that in the body the tension of vapour cannot, any more than an electrical current, be considered the cause of the production of force.

From the theory of disease developed in the preceding pages, it follows obviously, that a deceased condition once established, in any part of the body, cannot be made to disappear by the chemical action of a remedy. A limit may be put by a remedy to an abnormal process of transformation; that process may be accelerated or retarded; but this alone does not restore the normal (healthy) condition.

The art of the physician consists in the knowledge of the means which enable him to exercise an influence on the *duration* of the disease; and in the removal of all disturbing causes, the action of which strengthens or increases that of the actual cause of disease.

It is only by a just application of its principles that any theory can produce really beneficial results. The very same method of cure may restore health in one individual, which, if applied to another, may prove fatal in its effects. Thus in certain inflammatory diseases, and in highly muscular subjects, the antiphlogistic treatment has a very high value; while in other cases blood-letting produces unfavourable results. The vivifying agency of the blood must ever continue to be the most important condition in the restoration of a disturbed equilibrium, which result is always dependent on the saving of time; and the blood must, therefore, be considered and constantly kept in view, as the ultimate and most powerful cause of a lasting vital resistance, as well in the diseased as in the unaffected parts of the body.

It is obvious, moreover, that in all diseases where the formation of contagious matter and of exanthemata is accompanied by fever, two diseased conditions simultaneously exist, and two processes are simultaneously completed; and that the blood, as it were by re-action (*i. e.* fever) becomes a means of cure, as being the carrier of that substance (oxygen) without the aid of which the diseased products cannot be rendered harmless, destroyed, or expelled from the body; a means of cure by which, in short, neutralization or equilibrium is effected.

IV. Theory of Respiration.—During the passage of the venous blood through the lungs, the globules change their colour; and with this change of colour, oxygen is absorbed from the atmosphere. Further for every volume of oxygen absorbed, an equal volume of carbonic acid is, in most cases, given out.

The red globules contain a *compound of iron;* and no other constituent of the body contains iron.

Whatever change the other constituents of the blood undergo in the lungs, thus much is certain, that the globules of venous blood experience a change of colour, and that this change depends on the action of oxygen.

Now we observe that the globules of arterial blood retain their colour in the larger vessels, and lose it only during their passage through the capillaries. All those constituents of venous blood, which are capable of combining with oxygen, take up a corresponding quantity of it in the lungs. Experiments made with arterial serum have shown, that when in contact with oxygen it does not diminish the volume of that gas. Venous blood, in contact with oxygen, is reddened, while oxygen is absorbed; and a corresponding quantity of carbonic acid is formed.

It is evident that the change of colour in the venous globules depends on the combination of some one of their elements with oxygen; and that this absorption of oxygen is attended with the separation of a certain quantity of carbonic acid gas.

This carbonic acid is not separated from the serum; for the serum does not possess the property, when in contact with oxygen, of giving off carbonic acid. On the contrary, when separated from the globules, it absorbs from half its volume to an equal volume of carbonic acid, and, at ordinary temperatures, is not saturated with that gas. (See the article "Blut," in the "Handwörterbuch der Chemie, von Poggendorff, Wöhler, und Liebig, p. 877.)

Arterial blood, when drawn from the body, is soon altered; its florid colour becomes dark red. The florid blood, which owes its colour to the globules, becomes dark by the action of carbonic acid, and this change of colour affects the globules, for florid blood absorbs a number of gases which do not dissolve in the fluid part of the blood when separated from the globules. *It is evident, therefore, that the globules have the power of combining with gases.*

The globules of the blood change their colour in different gases; and this change may be owing either to a combination or to a decomposition.

Sulphuretted hydrogen turns them blackish green and finally black; and the original red colour cannot, in this case, be restored by contact with oxygen. Here a decomposition has obviously taken place.

The globules darkened by carbonic acid become again florid in oxygen, with disengagement of carbonic acid. The same thing takes place in nitrous oxide. It is clear that they have here undergone no decomposition, and, consequently, they possess the power of combining with gases, *while the compound they form with carbonic acid is destroyed by oxygen.* When left to themselves, out of the body, the compound formed with oxygen again becomes dark, but does not recover its florid colour a second time by the action of oxygen.

The globules of the blood contain a compound of iron. From the never-failing presence of iron in red blood, we must conclude, that it is unquestionably necessary to animal life; and, since physiology has proved, that the globules take no share in the process of nutrition, it cannot be doubted that they play a part in the process of respiration.

The compound of iron in the globules has the characters of an oxidized compound; for it is decomposed by sulphuretted hydrogen, exactly in the same way as the oxides or other analogous compounds of iron. By means of diluted mineral acids, peroxide (sesquioxide) of iron may be extracted, at the ordinary temperature, from the fresh or dried red colouring matter of the blood.

The characters of the compounds of iron may, perhaps, assist us to explain the share which that metal takes in the respiratory process. No other metal can be compared with iron, for the remarkable properties of its compounds.

The compounds of protoxide of iron possess the property of depriving other oxidized compounds of oxygen; while the compounds of peroxide of iron, under other circumstances, give up oxygen with the utmost facility.

Hydrated peroxide of iron, in contact with organic matters destitute of sulphur, is converted into carbonate of the protoxide.

Carbonate of protoxide of iron, in contact with water and oxygen, is decomposed; all the carbonic acid is given off, and, by absorption of oxygen, it passes into the hydrated peroxide, which may again be converted into a compound of the protoxide.

Not only the oxides of iron, but also the cyanides of that metal, exhibit similar properties. Prussian blue contains iron in combination with all the organic elements of the body; hydrogen and oxygen (water) carbon and nitrogen (cyanogen.)

When it is exposed to light, cyanogen is given off, and it becomes white; in the dark it extracts oxygen, and recovers its blue colour.

All these observations, taken together, lead to the opinion that the globules of arterial blood contain a compound of iron saturated with oxygen, which, in the living blood, loses its oxygen during its passage through the capillaries. The same thing occurs when it is separated from the body, and begins to undergo decomposition (to putrefy.) The compound, rich in oxygen, passes, therefore, by the loss of oxygen (reduction) into one far less charged with that element. One of the products of oxidation formed in this process is carbonic acid. The compound of iron in the venous blood possesses the property of combining with carbonic acid; and it is obvious, that the globules of the arterial blood, after losing a part of their oxygen, will, if they meet with carbonic acid, combine with that substance.

When they reach the lungs, they will again take up the oxygen they have lost; for every volume of oxygen absorbed, a corresponding volume of carbonic acid will be separated; they will return to their former state; that is, they will again acquire the power of giving off oxygen.

For every volume of oxygen which the globules can give off, there will be formed (as carbonic acid contains its own volume of oxygen, without condensation) neither more nor less than an equal volume of carbonic acid. For every volume of oxygen which the globules are capable of absorbing, no more carbonic acid can possibly be separated than the volume of oxygen can produce.

When carbonate of protoxide of iron, by the absorption of oxygen, passes into the hydrated peroxide, there are given off, for every volume of oxygen necessary to the change from protoxide to peroxide, four volumes of carbonic acid gas.

But from one volume of oxygen only one volume of cabronic acid can be *produced*, and the absorption of one volume of oxygen can only cause, directly, the *separation* of an equal body of carbonic acid. Consequently, the substance or compound which has lost its oxygen, during the passage of arterial into venous blood, must have been capable of absorbing or combining with carbonic acid; and we find, in point of fact, that the living blood is never, in any state, saturated with carbonic acid; that it is capable of taking up an additional quantity, without any apparent disturbance of the function of the globules. Thus, for example, after drinking effervescing wines, beer, or mineral waters, more carbonic acid must necessarily be expired than at other times. In all cases, where the oxygen of the arterial globules has been partly expended, otherwise than in the formation of carbonic acid, the amount of this latter gas expired will correspond exactly with that which has been formed; less, however, will be given out after the use of fat and of still wines, than after champagne.

According to the views now developed, the globules of arterial blood, in their passage through the capillaries, yield oxygen to certain constituents of the body. A small portion of this oxygen serves to produce the change of matter, and determines the separation of living parts and their conversion into lifeless compounds, as well as the formation of the secretions and excretions. The greater part, however, of the oxygen is employed in converting into oxidized compounds the newly formed substances, which no longer form part of the living tissues.

In their return towards the heart, the globules which have lost their oxygen combine with carbonic acid, producing venous blood; and, when they reach the lungs, an exchange takes place between this carbonic acid and the oxygen of the atmosphere.

The organic compound of iron, which exists in venous blood, recovers in the lungs the oxygen it has lost, and, in consequence of this absorption of oxygen, the carbonic acid in combination with it is separated.

All the compounds present in venous blood, which have any attraction for oxygen, are converted, in the lungs, like the globules, into more highly oxidized compounds; a certain amount of carbonic acid is formed, of which a part always remains dissolved in the serum of the blood.

The quantity of carbonic acid dissolved, or, of that combined with soda, must be equal in venous and arterial blood, since both have the same temperature; but arterial blood, when drawn, must, after a short time, contain a larger quantity of carbonic acid than venous blood, because the oxygen of the globules is expended in producing that compound.

Hence, in the animal organism, two processes of oxidation are going on; one in the lungs, the other in the capillaries. By means of the former, in spite of the degree of cooling, and of the increased evaporation which takes place there, the constant temperature of the lungs is kept up; while the heat of the rest of the body is supplied by the latter.

A man, who expires daily 13·9 oz. of carbon, in the form of carbonic acid, consumes, in 24 hours, 37 oz. of oxygen, which occupy a space equal to 807 litres=51,648 cubic inches (Hessian.)

If we reckon 18 respirations to a minute, we have, in 24 hours, 25,920 respirations; and, consequently, in each respiration, there are taken into the blood $\frac{51648}{25920}$=1·99 cubic inch of oxygen.

In one minute, therefore, there are added to the constituents of the blood 18 × 1·99= 35·8 cubic inches of oxygen, which, at the ordinary temperature, weigh rather less than 12 grains.

If we now assume, that in one minute 10 lbs. of blood pass through the lungs, (Müller, Physiologie, vol. i. p. 345,) and that this quantity of blood measures 320 cubic inches, then 1 cubic inch of oxygen unites with 9 cubic inches of blood, very nearly.

According to the researches of Dénis, Richardson, and Nasse (Handwörterbuch der Physiologie, vol. i. p. 138,) 10,000 parts of blood contain 8 parts of peroxide of iron. Consequently, 76,800 grains (10 lbs. Hessian) of blood contain 61·54 grains of peroxide of iron in arterial blood, = 55·14 of protoxide in venous blood.

Let us now assume that the iron of the globules of venous blood is in the state of protoxide. It follows, that 55·14 grains of protoxide of iron, in passing through the lungs, take up, in one minute, 6·40 grains of oxygen (the quantity necessary to convert it into peroxide.) But since, in the same time, the 10 lbs. of blood have taken up 12 grains of oxygen, there remain 5·60 grains of oxygen, which combine with the other constituents of the blood.

Now, 55·14 grains of protoxide of iron combine with 34·8 grains of carbonic acid, which occupy the volume of 73 cubic inches. It is obvious, therefore, that the amount of iron present in the blood, if in the state of protoxide, is sufficient to furnish the means of carrying or transporting twice as much carbonic acid as can possibly be formed by the oxygen absorbed in the lungs.

The hypothesis just developed rests on well-known observations, and, indeed, explains completely the process of respiration, as far as it depends on the globules of the blood. It does not exclude the opinion that carbonic acid may reach the lungs in other ways; that certain other constituents of the blood may give rise to the formation of carbonic acid in the lungs. But all this has no connexion with that vital process by which the heat necessary for the support of life is generated in every part of the body. Now it is this alone which, for the present, can be considered as the object truly worthy of investigation. It is not, indeed, uninteresting to inquire, why dark blood becomes florid by the action of nitre, common salt, &c.; but this question has no relation to the natural respiratory process.

The frightful effects of sulphuretted hydrogen, and of prussic acid, which, when inspired, put a stop to all the phenomena of motion in a few seconds, are explained in a natural manner by the well-known action of these compounds on those of iron, when alkalies are present; and free alkali is never absent in the blood.

Let us suppose that the globules lose their property of absorbing oxygen, and of afterwards giving up this oxygen and carrying off the resulting carbonic acid; such a hypothetical state of disease must instantly become perceptible in the temperature and other vital phenomena of the body. The change of matter will be arrested, while yet the vital motions will not be instantly stopped.

The conductors of force, the nerves, will convey, as before, to the heart and intestines the power necessary for their functions. This power they will receive from the muscular system, while, as no change of matter takes place in the latter, the supply must soon fail. As no change of matter occurs, no lifeless compounds are separated, neither bile nor urine can be formed; and the temperature of the body must sink.

This state of matters soon puts a stop to the process of nutrition, and sooner or later death must follow, but unaccompanied by febrile symptoms, which in this case is a very important fact.

This example has been selected in order to show the importance and probable advantage of an examination of the blood in analogous diseased conditions. It cannot be, in the slightest degree, doubtful that the function ascribed to the blood globules may be considered as fully explained and cleared up, if, in such morbid conditions, we shall discover a change in their form, structure, or chemical characters, a change which must be recognizable by the use of appropriate re-agents.

If we consider the force which determines the vital phenomena as a property of certain substances, this view leads of itself to a new and more rigorous consideration of certain singular phenomena, which these very substances exhibit, in circumstances in which they no longer make a part of living organisms.

APPENDIX:

CONTAINING THE ANALYTICAL EVIDENCE REFERRED TO IN THE SECTIONS IN WHICH ARE DESCRIBED THE CHEMICAL PROCESSES OF RESPIRATION, OF NUTRITION, AND OF THE METAMORPHOSIS OF TISSUES.

⁂ The Notes correspond with the numbers in parentheses in the text. All the Analyses quoted, which have the mark * attached, have been made in the chemical laboratory of the University of Giessen.

INTRODUCTION TO THE ANALYSES.

THE method formerly employed to exhibit the differences in composition of different substances, that, namely, of giving the proportions of the various elements in 100 parts, has been long abandoned by chemists; because it affords no insight into the relations which exist between two or more compounds. In order to give some proofs of this statement, we shall here state, in that form, the composition of aldehyde and acetic acid, of oil of bitter almonds and benzoic acid.

	Acetic acid.	Aldehyde.	Benzoic acid.	Oil of bitter almonds.
Carbon	40·00	55·024	69·25	79·56
Hydrogen	6·67	8·983	4·86	5·56
Oxygen	53·33	35·993	25.89	14·88

Now aldehyde is converted into acetic acid, and oil of bitter almonds into benzoic acid, simply by the addition of oxygen, without any change in regard to the other elements. This important relation cannot be traced in the mere numerical results of analysis as above given; but if the composition of the related compounds be expressed in formulæ, according to equivalents, the connexion in each case becomes obvious, even to him who knows no more of chemistry than that C represents an equivalent or combining portion of carbon, H an equivalent of hydrogen, and O an equivalent of oxygen.

$$\overbrace{\overset{\text{of acetic acid.}}{C^4H^4O^4.}\qquad\overset{\text{of aldehyde.}}{C^4H^4O^2.}}^{\text{Formula}}\qquad\qquad\overbrace{\overset{\text{of benzoic acid.}}{C^{14}H^6O^4.}\qquad\overset{\text{of oil of bitter almonds.}}{C^{14}H^6O^2.}}^{\text{Formula}}$$

These formulæ are exact expressions of the results of analysis, which, in each of the two cases quoted, refer to a fixed quantity of carbon; in one to 4 equivalents, in the other to 14. They show, that acetic acid differs from aldehyde, and benzoic acid from oil of bitter almonds, only in the proportion of oxygen.

Nor is it more difficult to understand the signification of the following formulæ.

$$\overset{\text{Cyamelide.}}{C^6N^3H^3O^6} = Cy^3(=\overset{\text{1 eq. cyanuric acid.}}{C^6N^3)O^3+3HO} = \overset{\text{3 eq. hydrated cyanic acid.}}{3(CyO+HO)} =$$
$$= C^6N^3H^3O^6 \qquad\qquad = C^6N^3H^3O^6.$$

(In these formulæ, N represents an equivalent of nitrogen, and Cy an equivalent of cyanogen. This latter substance being composed of 2 equivalents of carbon and 1 eq. of nitrogen, $Cy = C^2N$.)

The first formula (that of Cyamelide) is what is called an empirical formula, in which the relative proportions of the elements are, indeed, exactly known, but where we have not even a theory, far less any actual knowledge, of the order in which they are arranged. The second formula is intended to express the opinion that 3 eq. of cyanogen (= 6 eq. of carbon + 3 eq. of nitrogen) having united to form a compound atom or molecule, have combined with 3 eq. of oxygen and 3 eq. of water, to form 1 eq. of hydrated cyanuric acid. The third expresses the order in which the elements are supposed to be arranged in hydrated cyanic acid, the whole multiplied by 3. Each equivalent of cyanic acid is formed of 1 eq. of cyanogen, 1 eq. of oxygen, and 1 eq. of water; and hence the same number of atoms of each element, which together formed 1 eq. of cyanuric acid, is here so divided as to yield 3 eq. of cyanic acid.

We have here, therefore, the same absolute and relative amount of atoms of each element, arranged in three different ways; yet in each of these the proportions of the elements, calculated for 100 parts, must of course be the same. It is easy, therefore, to see the advantage we possess by the use of formulæ; that, namely, of exhibiting the relations existing between compounds of different composition; and that also of expressing the actual, probable, or possible differences between substances whose composition, in 100 parts, is the same, while their properties, as in the case above quoted, are perfectly distinct.

It does not come within our province here to explain the method or rule by which the composition of a substance, in 100 parts, (as it is always obtained in analysis,) is expressed in a formula; we shall only describe the rule for calculating, from a given formula, the composition in 100 parts. For this purpose it must be noted that C, in a chemical formula, signifies a weight of carbon expressed by the number 76·437 (according to the most recent determinations 75·8 or 75·0, a variation which has no effect whatever on the formulæ here adduced, all of which are calculated on the number 76·437), that H signifies a weight of hydrogen = 12·478; N a weight of nitrogen = 177·04; and lastly, O a weight of oxygen = 100.

The formula of proteine, $C^{48}N^6H^{36}O^{14}$, expresses, therefore,

48 times 76·437 = 3668·88 carbon,
6 times 177·040 = 1062·24 nitrogen,
36 times 12·478 = 449·26 hydrogen,
14 times 100·000 = 1400·00 oxygen.

The sum gives a weight of 6580·38 proteine.

Therefore—

			In 100 parts.
In 6580·38	parts of proteine are contained	3668·88 carbon	55·742
In 6580·38	ditto	1062·24 nitrogen	16·143
In 6580·38	ditto	449·26 hydrogen	6·827
In 6580·38	ditto	1400·00 oxygen	21·288
			100·000

The actual results of analysis, reduced to 100 parts, when compared with the above numbers, will show how far the assumed formula is corect; or, supposing the formula ascertained, they will show the degree of accuracy displayed by the experimenter. Thus the proportions in 100 parts, calculated from the formula, furnish an important check to the operator, and, conversely, the formula calculated from his results, when compared with other known formulæ, supplies a test of his accuracy, or of the purity of the substance analyzed.

NOTE (1,) p. 14.

CONSUMPTION OF OXYGEN BY AN ADULT.

An adult man.

According to	consumes of oxygen in 24 hours.		produces of carbonic acid in 24 hours.		Carbon contained. in the carbonic acid.	
	cubic in.	grains.	cubic in.	grains.	grains.	
Lavoisier and Seguin	46,037	15,661	14,930	8,584	2,820	French.
Menzies	51,480	17,625				English
Davy	45,504	15,751	31,680	17,811	4,853	do.
Allen and Pepys . .	39,600	13,464	39,600	18,612	5,148	do.

NOTE (2,) p. 14.

COMPOSITION OF DRY BLOOD (see Note 28.)

	In 100 parts.	In 4·8 lbs. Hessian = 36,864 grains.
Carbon . . .	51·96	19154·5
Hydrogen . . .	7·25	2672·7
Nitrogen . .	15·07	5555·4
Oxygen . .	21·30	7852·0
Ashes . .	4·42	1629·4
	100·00	36864·0

Grains.		Grains.		
19154·5	carbon form, with	50539·5	oxygen, carbonic acid.
2672·7	hydrogen do.	21415·8	do. water.
	Sum =	71955·3	do.
	Deduct oxygen present in blood . . . =	7852·0	

Remain 64103·3 grains of oxygen, required for the complete combustion of 4·8 lbs. of dry blood.

It is assumed in this calculation, that 24 lbs. of blood yield 4·8 lbs. (20 per cent.) of dry residue. The remainder, 80 per cent., is water.

NOTE (3,) p. 14.

DETERMINATION OF THE AMOUNT OF CARBON EXPIRED.

1. Analysis of

Fæces.

2·356 dry fæces left 0·320 ashes (13·58 per cent.)
0·352 dry fæces yielded 0·576 carbonic acid, and 0·218 water.

Lentils.

0·566 lentils, dried at 212°, yielded 0·910 carbonic acid, and 0·366 water.

Pease.

1·060 pease, dried at 212°, left 0·037 ashes.
0·416 do. do. yielded 0·642 carbonic acid, and 0·241 water.

Potatoes.

0·443 dried potatoes yielded 0·704 carbonic acid, and 0·248 water.

Black Bread (Schwarzbrod.)

0·302 dried black bread yielded 0·496 carbonic acid, and 0·175 water.
0·241 do. 0·393 do. 0·142 do.

From the above, which are the direct results of experiment, the composition in 100 parts is calculated as in the following table.

2. Composition

	Of Fæces.	Of Black Bread.		Of Potatoes.	Of Flesh.	
	Playfair.*	Bœckmann.*		Boussingault.	Bœckmann.*	
Carbon	45·24	45·09	45·41	44·1	43·944	(See note 28)
Hydrogen	6·88	6·54	6·45	5·8	6·222	
Nitrogen } Oxygen }	34·73	45·12	44·89	45·1	44·919	
Ashes	13·15	3·25	3·25	5·0	4·915	
	100·00	100·00	100·00	100·0	100·000	
Water	300·00					
	400·00					

	Of Pease. Playfair.*	Of Lentils. Playfair.*	Of Beans. Playfair.*
Carbon	35·743	37·38	38·24
Hydrogen	5·401	5·54	5·84
Nitrogen } Oxygen }	39·366	37·98	38·1
Ashes	3·490	3·20	3·71
Water	16·000	15·90	14·11
	100·000	100·00	100·00

	Fresh Meat. Bœckmann.*		Potatoes. Boussingault.*	Black Bread. Bœckmann.*		
Water . .	75	74·8	72·2	73·2	33	31·418
Dry Matter .	25	25·2	27·8	26·8	67	68·592
	100	100·0	100·0	100·0	100	100·000

3. Calculation,

with the help of the preceding data, of the amount of carbon expired by an adult man. The following results are deduced from observations made (see table) on the average daily consumption of food, by from 27 to 30 soldiers in barracks for a month, or by 855 men for one day. The food, consisting of bread, potatoes, meat, lentils, pease, beans, &c., was weighed, with the utmost exactness, every day during a month (including even pepper, salt, and butter;) and each article of food was separately subjected to ultimate analysis. The only exceptions, among the men, to the uniform allowance of food, were three soldiers of the guard, who, in addition to the daily allowance of 2 lbs. of bread, received, during each of the periods allotted for the pay of the troops, 2½ lbs. extra; and one drummer who, in the same period, left 2½ lbs. unconsumed. According to an approximative report by the sergeant-major, each soldier consumes daily, on an average, out of barracks, 3 oz. of sausage, ¾ oz. of butter, ½ pint of beer, and $\frac{1}{10}$ pint of brandy; the carbon of which articles amounts to more than double that of the fæces and urine taken together. In the soldier, the fæces amount daily, on an average, to 5½ oz.; they contain 75 per cent. of water, and the dry residue contains 45·24 per cent. of carbon, and 13·15 per cent. of ashes. 100 parts of fresh fæces consequently contain 11·31 per cent. of carbon, very nearly the same proportion as in fresh meat. In the calculation, the carbon of the fæces and of the urine has been assumed as equal to that of green vegetables, and of the food (sausages, butter, beer, &c.) consumed in the alehouse.

From the observations, as recorded in the table, the following conclusions are deduced.

Flesh.—Meat devoid of fat, if reckoned at 74 per cent. water, and 26 per cent. dry matter, contains in 100 parts very nearly 13·6 parts of carbon. Ordinary meat contains both fat and cellular tissue, which together amount to $\frac{1}{7}$th of the weight of the meat as bought from the butcher. The number of ounces consumed (by 855 men) was 4,448, consisting, therefore, of

3812·5 oz. of flesh, free from fat,	containing of carbon	518·5 oz.
635·5 oz. of fat and cellular tissue,	ditto	449·0 oz.
4448·0 oz.	In all, carbon	967·5 oz.

With the bones, the meat, as purchased, contains 29 per cent. of fixed matter, including bones; 4,448 oz. of flesh therefore contain 448 oz. of dry bones. These have not been included in the calculation, although, when boiled, they yield from 8 to 10 per cent. of gelatine, which is taken as food in the soup.

Fat.—The amount of fat consumed was 56 oz.; which, the carbon being calculated at 80 per cent., contain in all 44·8 oz. of carbon.

Lentils, pease and beans.—There were consumed 53·5 oz. of lentils, 185·5 oz. of pease and 218 oz. of beans. Assuming the average amount of carbon in these vegetables to be 37 per cent., the total quantity of carbon consumed in this form was 169·1 oz.

Potatoes.—100 parts of fresh potatoes contain 12·2 parts of carbon. In the 15·876 oz. of potatoes consumed, therefore, the amount of carbon was 1936·85 oz.

Bread.—855 men eat daily 855 times 32 oz., besides 36 lbs. of bread in the soup, which in all amounts to 27,936 oz. 100 oz. of fresh bread contain, on an average, 30·15 oz. of carbon; consequently the carbon consumed in the bread amounts to 8771·5 oz.

The total consumption, therefore, was,

In the meat	967·50	oz. of carbon
In the fat	44·80	ditto
In the lentils, pease, and beans . .	169·10	ditto
In the potatoes	1936·85	ditto
In the bread	8771·50	ditto
Consumed by 855 men . . .	11889·75	ditto
Consumed by 1 man	13·9	ditto

TABLE I. (to Note 3.)

Containing a Summary of the Victuals consumed during November, 1840, *by a Company of the Body Guard of the Grand Duke of Hesse Darmstadt.*

1840. November, in the period from the		No. of men supplied with food.	Beef.	Pork.	Potatoes.	Peas.	Beans.	Lentils.	Sour-krout.	Green vegetables.	Bread in Soup.	Salt.	Onions, Leeks, &c.	Pepper. Price in Kreutzers. 3kr.=1d.	Fat or Lard.	Vinegar.
			lbs.	lbs.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs.	lbs.	lbs.	lbs.	lbs.	kr.	oz.	pints.
1st to 5th		139	36	9	147 0	4 15½	3 7½	—	20	12	5	4½	4	2½	13⅓	—
6th to 10th		145	37	9	165 6	—	—	—	16	70	7½	5	3¼	2½	10⅔	—
11th to 15th		136	36	9	153 2	—	3 7½	—	16	42	7½	4½	3½	2	8	—
16th to 20th		136	37	9	177 10	3 5	3 7½	—	16	12	6	4½	4¼	3½	13⅓	—
21st to 25th		147	39	Sausages. 7½	171 8	—	—	3 5½	—	36	7½	5½	5½	2½	5⅓	1½
26th to 30th		152	30	19½	177 10	3 5	3 7½	—	32	—	2½	4	3¾	2½	5⅓	—
Total,		855	215	63	992 4	11 9½	13 14	3 5½	100	172	36	28	20¼	15½	56	1½
The average No. of men daily fed is $\frac{855}{30}$=28½, therefore each man had	Monthly		lbs. $7\frac{31}{57}$	lbs. $2\frac{12}{57}$	lbs. oz. 34 13	oz. $6\frac{87}{171}$	oz. $7\frac{135}{171}$	oz. $1\frac{150}{171}$	lbs. oz. 3 $11\frac{91}{151}$	lbs. $6\frac{6}{171}$	lb. $1\frac{15}{57}$	lb. $\frac{56}{57}$	oz. $11\frac{7}{19}$	kr. $\frac{31}{57}$	oz. $1\frac{55}{57}$	pint. $\frac{3}{57}$
	Daily		oz. $4\frac{4}{171}$	$1\frac{153}{855}$ oz.	lb. oz. 1 $2\frac{54}{95}$	oz. $\frac{371}{1710}$	oz. $\frac{222}{855}$	oz. $\frac{107}{1710}$	oz. $1\frac{149}{151}$	oz. $3\frac{187}{855}$	lb. $\frac{36}{855}$	lb. $\frac{28}{255}$	oz. $\frac{324}{855}$	kr. $\frac{31}{1710}$	oz. $\frac{56}{855}$	pint. $\frac{3}{1710}$

N. B.—As all the weights mentioned in the text of this work are Hessian pounds and ounces, the different articles in this table have been reduced to the same weights, excepting the Pepper and Vinegar, the amount of both of which is so small that they may be omitted, without affecting the general result. For the benefit of those who may wish to reduce these weights to avoirdupois weight, it may here be mentioned, that 1 lb. Hessian=16 oz. Hessian=7680 grains Hessian=7712 grains avoirdupois. Consequently, since the 1 lb. avoirdupois is=7000 grains Troy, 1 lb. avoirdupois : 1 lb. Hessian : : 7000 : 7712, or as 1 : 1·1017; and 1 oz. Hessian=482 grains Troy (1 oz. Troy is=480 grains,) while 1 oz. avoirdupois is=437·5 grains Troy.

The fæces of a soldier weigh 5·5 oz., and contain, in the fresh state, 11 per cent. of carbon. For 86 kreutzer (about 2*s*. 5*d*. sterling,) there may be bought, on an average, 172 lbs. of vegetables, such as cabbages, greens, turnips, &c.; 25 maas of sour krout weigh 100 lbs.; and for 48½ kreutzer (1*s*. 5*d*. sterling,) there are brought, on an average, 24¼ lbs. of onions, leeks, celery, &c.* 855 men consumed

Of green vegetables	2,802 oz.
Of sour krout	1,600
Of onions, &c.	388
.n all	4,790
And one man	5·6 oz.

For this reason, the carbon of the last mentioned articles of food has been assumed as equal to that of the fæces and urine. Sausages, brandy, beer, in short, the small quantity of food taken irregularly in the alehouse, has not been included in the calculation.

The daily allowance of bread, being uniformly 2 lbs. per man, with the exceptions formerly mentioned, has not been inserted in the table, which includes only those matters of which, from the daily allowance being variable, an average was required. The small quantity of bread in the table is that given in the soup, which is over and above the daily supply.

NOTE (4.) See next page.

NOTE (5,) p. 15.

TEMPERATURE OF THE BLOOD AND FREQUENCY OF THE PULSE.

According to Prevost and Dumas.

	The mean temperature is F.	The frequency	
		of the pulse in the minute.	of the respiration in the minute.
In the Pigeon . .	107·6° . .	136 . .	34
Common Fowl .	106·7 . .	140 . .	30
Duck . . .	108·5 . .	170 . .	21
Raven . . .	108·5 . .	110 . .	21
Lark . . .	117·2 . .	200 . .	22
Simia Callitriche .	95·9 . .	90 . .	30
Guinea Pig . .	100·4 . .	140 . .	36
Dog . . .	99·3 . .	90 . .	28
Cat	101·3 . .	100 . .	24
Goat . . .	102·5 . .	84 . .	24
Hare	100·4 . .	120 . .	36
Horse . . .	98·2 . .	56 . .	16
Man	98·6 . .	72 . .	18
Man (Liebig) . .	97·7° . .	65 . .	17
Woman (Liebig) .	98·2 . . .	60 . .	15

The temperature of a child is 102·2°.

The temperature of the human body, in the mouth or in the rectum, for example, is from 97·7° to 98·6°. That of the blood (Majendie) is from 100·6° to 101·6°. As a mean temperature, 99·5° has been adopted in this work, page 15.

NOTE (6,) p. 20.

The prisoners in the house of arrest of Giessen receive daily 1½ lb. of bread (24 oz.,) which contain 7¼ oz. of carbon. They receive, besides, 1 lb. of soup daily, and on each alternate day, 1 lb. of potatoes.

1½ lb. of bread contains	7·25	oz. of carbon.
1 lb. of soup contains	0·75	ditto.
½ lb. of potatoes contains	1·00	ditto.
Total	9·00	ditto.†

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* In the original table, the quantities of these vegetables are entered according to their value in kreutzers, but they are here calculated by weight from the above data, as this appeared better adapted for comparison in this country than the prices would have been.—Ed.

† At page 36 the carbon contained in the daily food of these prisoners is calculated at 8½ oz., and

TABLE II.—Note (4,) p. 14. a

FOOD CONSUMED BY A HORSE IN TWENTY-FOUR HOURS.

Articles of food.	Weight in the fresh state.	Weight in the dry state.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Salts and earthy matters.
Hay	7500	6465	2961·0	323·2	2502·0	97·0	581·8
Oats	2270	1927	977·0	123·3	707·2	42·4	77·1
Water	16000	—	—	—	—	—	13·3
Total	25770	8392	3938·0	446·5	3209·2	139·4	672·2

FOOD CONSUMED BY A COW IN TWENTY-FOUR HOURS.

Articles of food.	Weight in the fresh state.	Weight in the dry state.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Salts and earthy matters.
Potatoes	15000	4170	1839·0	241·9	1830·6	50·0	208·5
After Grass	7500	6315	2974·4	353·6	2204·0	151·5	631·5
Water	60000	—	—	—	—	—	50·0
Total	82500	10485	4813·4	595·5	4034·6	201·5	889·0

EXCRETIONS OF A HORSE IN TWENTY-FOUR HOURS.

Excretions.	Weight in the fresh state.	Weight in the dry state.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Salts and earthy matters.
Urine	1330	302	108·7	11·5	34·1	37·8	109·9
Excrements	14250	3525	1364·4	179·8	1328·9	77·6	574·6
Total	15580	3827	1472·9	191·3	1363·0	115·4	684·5
Total from the previous part of this Table.	25770	8392	3938·0	446·5	3209·2	139·4	672·2
Difference	10190	4565	2465·1	255·2	1846·2	24·0	12·3
+ or —	—	—	—	—	—	—	+

EXCRETIONS OF A COW IN TWENTY-FOUR HOURS.

Excretions.	Weight in the fresh state.	Weight in the dry state.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Salts and earthy. matters.
Excrements.	28413	4000·0	1712·0	208·0	1508·0	92·0	480·0
Urine	8200	960·8	261·4	25·0	253·7	36·5	384·2
Milk	8539	1150·6	628·2	99·0	321·0	46·0	56·4
Total	45152	6111·4	2601·6	332·0	2082·7	174·5	920·6
Total of first part of this Table.	82500	10485·0	4813·4	595·5	4034·6	201·5	889·0
Difference	37348	4374·6	2211·8	263·5	1951·9	27·0	31·6
+ or —	—	—	—	—	—	—	+

a Boussingault, Ann. de Ch. et de Phys., LXX., 136 The weights in this table are given in grammes. 1 gramme=15·44 grains Troy, very nearly.

NOTE (7,) p. 21.

COMPOSITION OF THE FIBRINE AND ALBUMEN OF BLOOD. a.

	Albumen from Serum of Blood. Scherer.*			Fibrine. Scherer.*		Mulder.
	I.	II.	III.	I.	II.	III.
Carbon	53·850	55·461	56·097	53·671	54·454	54·56
Hydrogen	6·983	7·201	6·880	6·878	7·069	6·90
Nitrogen	15·673	15·673	15·681	15·763	15·762	15·72
Oxygen Sulphur Phosphorus	23·494	21·655	22·342	23·688	22·715	22·82

a Annalen der Chem. und Pharm., XXVIII., 74, and XL., 33, 36.

For additional analyses of animal fibrine and albumen, see Note (27,) which also contains analyses of the various animal tissues.

NOTE (8,) p. 22.

COMPOSITION OF VEGETABLE FIBRINE, VEGETABLE ALBUMEN, VEGETABLE CASEINE, AND VEGETABLE GLUTEN.

	VEGETABLE FIBRINE. Sherer*a.			GLUTEN, As obtained from wheat flour. Jones.*b	Marcet.c	Boussingault.
	I.	II.	III.	IV.	I.	II.
Carbon	53·064	54·603	54·617	53·83	55·7	53·5
Hydrogen	7·132	7·302	7·491	7·02	14·5	15·0
Nitrogen	15·359	15·809	15·809	15·58	7·8	7·0
Oxygen Sulphur Phosphorus	24·445	22·285	22·083	23·56	22·0	24·5

a Ann. der Chem. und Pharm., XL., 7. b Ibid., XL., 65. c L. Gmelin's Theor. Chemie, II., 1092.

VEGETABLE ALBUMEN, a.

	From Rye. Jones.*	Wheat. Jones.*	Gluten. Varrentrapp & Will.*	Almonds. Jones.*
Carbon	54·74	55·01	54·85	57·03
Hydrogen	7·77	7·23	6·98	7·53
Nitrogen	15·85	15·92	15·88	13·48
Oxygen Sulphur Phosphorus	21·64	21·84	22·39	21·96

	Boussingault.	Varrentrapp and Will.*
Carbon	52·7	—
Hydrogen	6·9	—
Nitrogen	18·4	15·70
Oxygen, &c.	22·0	—

a Ann. der Chem. und Pharm., XI., 66, and XXXIX., 291.

VEGETABLE CASEINE.a

	Scherer.*	Jones.*	Sulphate of Caseine and Potash. Varrentrapp and Will.	
Carbon	54·138	55·05	51·41	51·24
Hydrogen	7·156	7·59	7·83	6·77
Nitrogen	15·672	15·89	14·48	13·23
Oxygen, &c.	23·034	21·47	—	—

a Ann. der Chem. und Pharm., XXXIX., 291, and XL., 8 and 67.

VEGETABLE GLUTEN.

	Jones.*a	Boussingault.	
Carbon	55·22	54·2	52·3
Hydrogen	7·42	7·5	6·5
Nitrogen	15·98	13·9	18·9
Oxygen, &c.	21·38	24·4	22·3

a Ann. der Chem. und Pharm., XL., 66.

The pure gluten, analyzed by Jones, was that portion of the raw gluten from wheat flour which is soluble in hot alcohol. The insoluble portion is vegetable fibrine, the analysis of which has been already given.

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*The appendix in the original makes the number also 8·5, apparently by an error in adding up the above numbers, which yield the sum of 9 oz. Possibly there may be an error in excess in the proportion of carbon calculated for the soup, which, in that case, ought to be 0·25 oz.—EDITOR.

NOTE (9,) p. 24.

COMPOSITION OF ANIMAL CASEINE.[a]

	Scherer.				
	From fresh milk.	From sour milk.		From milk by acetic acid.	Albuminous substance in milk.[b]
	I.	II.	III.	IV.	V.
Carbon .	54·825	54·721	54·665	54·580	54·507
Hydrogen .	7·153	7·239	7·465	7·352	6·913
Nitrogen .	15·628	15·724	15·724	15·696	15·670
Oxygen Sulphur .	22·394	22·316	22·146	22·372	22·910

[a] Ann. der Chem. und Pharm., XL., 40 et seq.

[b] This substance, called, in German, *zieger*, is contained in the whey of milk after coagulation by an acid. It is coagulated by heat, and very much resembles albumen.

	Mulder.[a]
Carbon	54·96
Hydrogen	7·15
Nitrogen	15·89
Oxygen	21·73
Sulphur	0·36

[a] For the analysis of vegetable caseine, see the preceding note.

NOTE (10,) p. 27.

AMOUNT OF MATTER SOLUBLE IN ALCOHOL IN THE SOLID EXCREMENTS OF THE HORSE AND COW. (WILL.*)

18·3 grammes of dried horse-dung lost, by the action of alcohol, 0·995 gramme. The residue, when dry, had the appearance of saw-dust, after it had been deprived, by boiling, of all soluble matter.

14·98 grammes of dry cow-dung lost, by the same treatment, 0·625 gramme.

NOTE (11,) p. 28.

COMPOSITION OF STARCH. [a]

		Strecker.*			
	Calculated $C_{12}H_{10}O_{10}$.	From Peas.	From Lentils.	From Beans.	From Buckwheat.
Carbon . .	44.91	44·33	44·46	44·16	44·23
Hydrogen . .	6·11	6·57	6·54	6·69	6·40
Oxygen . .	48·98	49·09	49·00	49·15	49·37

	Strecker.*			
	From maize.	From horse-chestnuts.	From wheat.	From rye.
Carbon . . .	44·27	44·44	44·26	44·16
Hydrogen .	6·67	6·47	6·70	6·64
Oxygen . .	49·06	49·08	49·04	49·20

	Strecker.*			
	From rice.	From dahlia-roots.	From unripe apples.	From unripe pears.
Carbon . .	44·69	44·13	44·10	44·14
Hydrogen . .	6·36	6·56	6·57	6·75
Oxygen . .	48·95	49·31	49·33	49·11

	From potatoes.		From arrow-root.	From yams.[a]
	Berzelius.	Gay Lussac & Thenard.	Prout.	Ortigosa.
Carbon .	44·250	43·55	44·40	44·2
Hydrogen .	6·674	6·77	6·18	6·5
Oxygen .	49·076	49·68	49·42	49·3

[a] The starch employed for the analyses, made by Strecker and Ortigosa, was prepared from the chemical laboratory at Giessen, from the respective seeds, bulbs, and fruits.

NOTE (12,) p. 28.

COMPOSITION OF GRAPE SUGAR. (STARCH SUGAR.)

	From grapes.[a]	From starch.[b]	From honey.[c]	Calculated.
	De Saussure.		Prout.	$C_{12}H_{14}O_{14}$.
Carbon .	36·71	37·29	36·36	36·80
Hydrogen .	6·78	6·84	7·09	7·01
Oxygen .	56·51	55·87	56·55	56·19

[a] Ann. de Chimie, XI., 381. [b] Ann. of Philosophy, VI., 426. [c] Philosoph. Trans. 1827, 373.

NOTE (13,) p. 29.

COMPOSITION OF SUGAR OF MILK.

	Gay Lussac and Thenard.	Prout.	Brunn.	Berzelius.	Liebig.*	Calculated $C_{12}H_{12}O_{12}$.
Carbon .	38·825	40·00	40·437	39·474	40·00	40·46
Hydrogen	7·341	6·66	6·711	7·167	6·73	6·61
Oxygen .	53·834	53·34	52·852	53·359	53.27	52·93

NOTE (14,) p. 29.

COMPOSITION OF GUM.

	Gay Lussac and Thenard.	Goebel.	Berzelius.	Calculated. $C_{12}H_{11}O_{11}$.
Carbon ·	42·23	42·2	42·682	42·58
Hydrogen	6·93	6·6	6·374	6·37
Oxygen ·	50·84	51·2	50·944	51·05

NOTE (15,) p. 29.

ANALYSIS OF OATS. (Boussingault.)[a]

100 parts of oats contain of dry matter . . .	82·9
Ditto water	17·1
	100·0

100 parts of oats dried at 212° = 117·7 parts dried at the ordinary temperature contain

Carbon . .	50·7
Hydrogen . .	6·4
Oxygen . .	36·7
Nitrogen . .	2·2
Ashes . .	4·0
	100·0
Water . .	17·7

Oats dried in the air 117·7 contain, in 100 parts, 1·867 of nitrogen.

[a] Ann. de Chimie et de Phys., LXXI., 130.

ANALYSIS OF HAY.

100 parts of hay dried in the air contain 86 of dry matter,
14 of water.

100

100 parts of hay dried at 212° = 116·2 parts dried in air, contain

Carbon . .	45·8
Hydrogen . .	5·0
Oxygen . .	38·7
Nitrogen . .	1·5
Ashes . . .	9·0
	100·0
	16·2 water,
	116·2 hay dried in the air.

100·0 of hay dried at the ordinary temperature contain 1·29 of nitrogen.
240 oz. of such hay = 15 lbs. contain . . 3·095 oz. of nitrogen.
72 oz. of oats = 4½ lbs. contain . 1·34 ditto
Total . . . 4·435 ditto

NOTE (16,) a, p. 30.

AMOUNT OF CARBON IN FLESH AND IN STARCH.

100 parts of starch contain 44 of carbon; therefore, 64 oz. (4 lbs.) contain 28·16 oz. of carbon.

100 parts of fresh meat contain 13·6 of carbon (see Note III.;) hence 240 oz. (15 lbs.) contain 32·64 oz. of carbon.*

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* By an error in calculation in the original, the amount of carbon in 15 lbs. of meat is stated to be 27·64 oz. It follows, that the carbon of 4 lbs. of starch is not equal, as stated in the text, to that of 15 lbs. of flesh, but to that of 13 lbs. This difference, however, is not sufficient to affect the argument at p. 32.—EDITOR.

NOTE (16,) b, p. 32.

COMPOSITION OF

	Hog's Lard.	Mutton fat. Chevreul. *a*	Human fat.
Carbon . . .	79·098	78·996	79·000
Hydrogen . .	11·146	11·700	11·416
Oxygen . . .	9·756	9·304	9·584

a Recherches Chim., sur les Corps Gras. Paris. 1823.

NOTE (17,) p. 32

COMPOSITION OF CANE SUGAR.

	According to					
	Berzelius.	Prout.	W. Crum.	Liebig.	Gay Lussac & Thenard.	Calculated $C_{12}H_{11}O_{11}$
Carbon	42·225	42·86	42·14	42·301	42·47	42·58
Hydrogen	6·600	6·35	6·42	6·384	6·90	6·37
Oxygen	51·175	50·79	51·44	51·315	50·63	51·05

For the composition of gum and of starch, see Notes (14) and (11)

NOTE (18,) p. 32.

COMPOSITION OF CHOLESTERINE.

	According to			
	Chevreul. *a*	Couerbe. *b*	Marchand.	Calculated $C_{36}H_{32}O$.
Carbon . .	85·095	84·895	84·90	84·641
Hydrogen .	11·880	12·099	12·00	12·282
Oxygen . .	3·025	3·006	3·10	3·077

a Recherches sur les Corps Gras, p. 185. *b* Ann. de Ch. et de Phys. LVI., p. 164.

NOTE (19,) p. 33.

THE PRODUCTION OF WAX FROM SUGAR.*

As soon as the bees have filled their stomach, or what is called the honey bladder, with honey, and cannot deposit it for want of cells, the honey passes gradually in large quantity into the intestinal canal, where it is digested. The greater part is expelled as excrement; the rest enters the fluids of the bee. In consequence of this great flow of juices a fatty substance is produced, which oozes out on the eight spots formerly mentioned, which occur on the four lower scales of the abdominal rings, and soon hardens into laminæ of wax. On the other hand, when the bees can deposit their honey, only so much enters the intestinal canal as is necessary for their support. The honey bladder need not be filled with honey longer than forty hours in order to bring to maturity, on the eight spots, eight laminæ of wax, so that the latter fall off. I made the experiment of giving to bees, which I had enclosed in a box with their queen about the end of September, dissolved sugar candy instead of honey. Out of this food laminæ of wax were formed; but these would not separate and fall off readily, so that the mass, which continued to ooze out, remained, in most of the bees, hanging to the upper laminæ: and the laminæ of wax became as thick as four under ordinary circumstances. The abdominal scales of the bees were, by means of the wax, distinctly raised, so that the waxen laminæ projected between them. On examination, I found that these thick laminæ, which under the microscope exhibited several lamellæ, had a sloping surface downwards near the head, and upwards in the vicinity of the tail. The first waxen laminæ, therefore, must have been pushed downwards by the second, because, where the abdominal scales are attached to the skin, there is no space for two laminæ, the second by the third, and thus the inclined surfaces on the sides of the thick laminæ had been produced. I saw distinctly from this, that the first formed laminæ are detached by those which followed. The sugar had been converted into wax by the bees, but it would seem that there was some imperfection in the process, as the laminæ did not fall off, but adhered to the succeeding ones.

In order to produce wax in the manner described, the bees require no pollen, but only honey. I have placed, even in October, bees in an empty hive, and fed them with honey; they soon formed comb, although the weather was such that they could not leave the hive. I cannot, therefore, believe that pollen furnishes food for the bees, but I think they only swallow it, in order, by mixing it with honey and water, to prepare the liquid food for the grubs. Besides, bees often starve in April, when their stock of honey is consumed, and when they can obtain in the fields abundance of pollen, but no honey.

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* From F. W. Gundlach's Natural History of Bees, p. 115. Cassel, 1842 We are acquainted with no more beautiful or convincing proof of the formation of fatty matter from sugar than the following process of the manufacture of wax by the bees, as taken from observation.

When pressed by hunger they tear the nymphæ out of the cells, and gnaw them in order to support life by the sweet juice which they contain. But, if in this condition they are not artificially fed, or if the fields do not soon yield their proper food, they die in the course of a few days. Now, if the pollen were really nourishment for bees, they ought to be able to support life on it, mixed with water.

Bees never build honeycomb unless they have a queen, or are provided with young out of which they can educate a queen. But if bees be shut up in a hive without a queen, and fed with honey, we can perceive in forty-eight hours that they have laminæ of wax on their scales, and that some have even separated. The building of cells is therefore voluntary, and dependent on certain conditions, but the oozing out of wax is involuntary.

One might suppose that a large proportion of these laminæ must be lost, since the bees may allow them to fall off, out of the hive as well as in it; but the Creator has wisely provided against such a loss. If we give to bees engaged in building cells honey in a flat dish, and cover the dish with perforated paper, that the bees may not be entangled in the honey, we shall find, after a day, that the honey has disappeared, and that a large number of laminæ are lying on the paper. It would appear as if the bees, which have carried off the honey, had let fall the scales; but it is not so. For, if above the paper we lay two small rods, and on these a board, overhanging the dish on every side, so that the bees can creep under the board and obtain the honey, we shall find next day the honey gone, but no laminæ on the paper; while laminæ will be found in abundance on the board above. The bees, therefore, which go for and bring the honey, do not let fall the laminæ of wax, but only those bees which remain hanging to the top of the hive. Repeated experiments of this kind have convinced me that the bees, as soon as their laminæ of wax are mature, return to the hive and remain at rest, just as caterpillars do, when about to change. In a swarm that is actively employed in building we may see thousands of bees hanging idly at the top of the hive. These are all bees whose laminæ of wax are about to separate. When they have fallen off, the activity of the bee revives, and its place is occupied for the same purpose by another.

(From page 28 of the same work.) In order to ascertain how much honey bees require to form wax, and how often, in a swarm engaged in building, the laminæ attain maturity and fall off, I made the following experiment, which appears to me not uninteresting.

On the 29th of August, 1841, at a time when the bees could obtain in this district no farther supply of honey from the fields, I emptied a small hive, placed the bees in a small wooden hive, having first selected the queen bee, and shut her up in a box, furnished with wires, which I placed in the only door of the hive, so that no embryoes could enter the cells. I then placed the hive in a window, that I might be able to watch it.

At 6 P. M. I gave the bees 6 oz. of honey run from the closed cells, which had thus the exact consistence of freshly made honey. This had disappeared next morning. In the evening of the 30th I gave the bees 6 oz. more, which, in like manner, was removed by the next morning; but already some laminæ of wax were seen lying on the paper with which the honey was covered. On the 31st August and the 1st September the bees had in the evening 10 oz., and on the 3d of September in the evening 7 oz.; in all, therefore, 1 lb. 13 oz. of honey, which had run cold out of cells which the bees had already closed. On the 5th of September I stupified the bees, by means of puff-ball and counted them. Their number was 2,765, and they weighed 10 oz. I next weighed the hive, the combs of which were well filled with honey, but the cells not yet closed; noted the weight, and then allowed the honey to be carried off by a strong swarm of bees. This was completely effected in a few hours. I now weighed it a second time, and found it 12 oz. lighter; consequently the bees still had in the hive 12 oz. of the 29 oz. of honey given to them. I next extracted the combs, and found that their weight was ⅝ of an ounce. I then placed the bees in another box, provided with empty combs, and fed them with the same honey as before. In the first few days they lost daily rather more than 1 oz. in weight, and afterwards half an ounce daily, which was owing to the circumstance, that from the digestion of so much honey, their intestinal canal was loaded with excrements; for 1,170 bees, in autumn, when they have been but a short time confined to the hive, weigh 4 oz.; consequently 2,765 bees should weigh 9 oz. But they actually weighed 10 oz., and therefore had within them 1 oz. of excrement, for their honey bladders were empty. During the night the weight of the box did not diminish at all, because the small quantity of honey the bees had deposited in the cells, having already the proper consistence, could not lose weight by evaporation, and because the bees could not then get rid of their excrements. For this reason, the loss of weight occurred always during the day.

If, then, the bees, in seven days, required 3½ oz. of honey to support and nourish their bodies, they must have consumed 13½ oz. of honey in forming ⅝ of an ounce of wax; and consequently, to form 1 lb. of wax, 20 lbs. of honey are required. This is the reason why the strongest swarms in the best honey seasons, when other hives, that have no occasion to build, often gain in one day 3 or 4 lbs. in weight, hardly become heavier, although their activity is boundless. All that they gain is expended in making wax

This is a hint for those who keep bees, to limit the building of comb. Cnauf has already recommended this, although he was not acquainted with the true relations of the subject. From 1 oz. of wax, bees can build cells enough to contain 1 lb. of honey.

100 laminæ of wax weigh 0·024 gramme (rather more than ⅓ of a grain,) consequently, 1 kilogramme (= 15,360 grains) will contain 4,166,666 laminæ. Hence, ⅝ of an ounce will contain 81,367 laminæ. Now this quantity was produced by 2,765 bees in six days; so that the bee requires for the formation of its 8 laminæ (one crop) about thirty-eight hours, which agrees very well with my observations.

The laminæ, when formed, are as white as bleached wax. The cells also, at first, are quite white, but they are coloured yellow by the honey, and still more by the pollen. When the cold weather comes on, the bees retire to the hive under the honey, and live on the stock they have accumulated.

P. 54. Many believe that bees are hybernating animals; but the opinion is quite erroneous. They are lively throughout the winter; and the hive is always warm in consequence of the heat which they generate. The more numerous the bees in a hive, the more heat is developed; and hence strong hives can resist the most intense cold. It once happened that I forgot to remove from the door, which was unusually large, of a hive in winter, a perforated plate of tinned iron, which I had fastened over the opening to diminish the heat in July; and yet this hive came well through the winter, although the cold was very severe, having been for several days so low as 0°. But I had added to this hive the bees of two other hives! When the cold is very intense, the bees begin to hum. By this means respiration is accelerated and the developement of heat increased. If, in summer, bees without a queen are shut up in a glass box, they become uneasy and begin to hum. So much heat is by this means developed, that the plates of glass become quite hot. If the door be not opened in this case, or if air be not admitted, and if the glass be not cooled by the aid of water, the bees are soon suffocated.

COMPOSITION OF BEES' WAX.

	Gay Lussac and Thenard.*a*	De Saussure.*b*	Oppermann.*c*	Ettling.*d*	Hess.*e*	Calculated $C_{20}H_{20}O$.
Carbon .	81·784	81·607	81·291	81·15	81·52	81·38
Hydrogen .	12·672	13.859	14·073	13·75	13·23	13·28
Oxygen .	5·544	4·534	4·636	5·09	5·25	5·34

a Traité de Chimie, par M. Thénard, 6me. Ed. IV., 477.
b Ann. de Ch. et de Phys. XIII., 310. *c* Ibid. XLIX., 224.
d Annal. der Pharm., II., 267. *e* Ibid. XXVII., 6.

NOTE (21) a, p. 36.

COMPOSITION OF HYDRATED CYANURIC ACID, OR HYDRATED CYANIC ACID, AND OF CYAMELIDE, IN 100 PARTS, ACCORDING TO THE ANALYSIS OF WÖHLER AND LIEBIG.*a

	Cyanuric acid, cyanic acid, cyamelide.
Carbon	28·19
Hydrogen	2·30
Nitrogen	32·63
Oxygen	36·87

a Poggendorff's Annalen, XX., 375 et seq.

NOTE (21) b. p. 36.

COMPOSITION OF ALDEHYDE, METALDEHYDE, AND ELALDEHYDE.*a*

	Aldehyde. Liebig.*	Metaldehyde. Fehling.*	Elaldehyde. Fehling.*		Calculated $C_4H_4O_2$.
Carbon .	55·024	54·511	54·620	54·467	55·024
Hydrogen .	8·983	9·054	9·248	9·075	8·983
Oxygen .	35·993	36·435	36·132	36·458	35·993

a Ann. der Pharm., XIV., 142, und XXVII., 319.

NOTE (22,) p. 37.

COMPOSITION OF PROTEINE.

	From the crystalline lens.	From albumen. Scherer.*a*	From fibrine.
Carbon . .	55·300	55·100	54·848
Hydrogen . .	6·940	7·055	6·959
Nitrogen .	16·216	15·966	15·847
Oxygen . .	21·544	21·819	22·346

a Ann. der Chem. und Pharm., XL., 43.

	Scherer.*a*				
	From hair.		From horn.		Calculated $C_{48}H_{36}N_6O_{14}$.
Carbon . . .	54·746	55·150	55·408	54·291	55·742
Hydrogen . . .	7·129	7·197	7·238	7·082	6·827
Nitrogen . .	1·727	15·727	15·593	15·593	16·143
Oxygen . . .	22·398	21·926	21·761	23·034	21·228

a Ann. der Chem. und Pharm., XL., 43.

	From vegetable albumen.	From fibrine.	From albumen.	From cheese.
	Mulder.*a*			
Carbon	54·99	55·44	55·30	55·159
Hydrogen	6·87	8·95	6·94	7·176
Nitrogen	15·66	16·05	16·02	15·857
Oxygen	22·48	21·56	21·74	21·808

a Ann. de Pharm., XXVIII., 75.

NOTE (23,) p. 37.

COMPOSITION OF THE ALBUMEN OF THE YOLK AND OF THE WHITE OF THE EGG.*a*

	From the yolk. Jones.* I.	From the yolk. Jones.* II.	From the white. Scherer.*
Carbon . .	53·72	53·45	55·000
Hydrogen . .	7·55	7·66	7·073
Nitrogen . .	13·60	13·34	15·920
Oxygen Sulphur Phosphorus .	25·13	25·55	22·007

a Ann. der Chem. und Pharm. XL., 36, ibid. 67.

NOTE (24,) p. 38.

COMPOSITION OF LACTIC ACID.

	$C_6H_5O_5$.
Carbon	44·90
Hydrogen	6·11
Oxygen	48·99

NOTE (25,) p. 39.

GAS FROM THE ABDOMEN OF COWS AFTER EATING CLOVER TO EXCESS, OBTAINED BY PUNCTURE.

a Examined by Lameyran and Frémy. *b* By Vogel. *c* By Pflüge.

	Air.	Carbonic acid.		Inflammable gas.	Sulphuretted hydrogen.
a	5	5	—	15	80 Vol. in 100 Vol.
b	25	—	27	48	—
c	—	—	60	40	—
c	—	—	20	80	—

NOTE (26,) p. 40.

MAGENDIE FOUND IN THE STOMACH AND INTESTINES OF EXECUTED CRIMINALS:

a In the case of an individual who had taken food in moderation one hour previous to death; *b*, in the case of one who had done so two hours previously; and *c*, in the case of a third, who had done so four hours previous to execution.

		100 Volumes of the gas contained: Oxygen.	Nitrogen.	Carbonic acid.	Inflammable gas.
a	From the stomach	11·00 Vol.	71·45	14·00	3·55
	— small intestines	00·00	20·03	24·39	55·53
	— large intestines	00·00	51·03	43·50	5·47
b	From the stomach	00·00	00·00	00·00	00·00
	— small intestines	00·00	8·85	40·00	51·15
	— large intestines	00·00	18·40	70·00	11·60
c	From the stomach	00·00	00·00	00·00	00·00
	— small intestines	00·00	66·60	25·00	8·40
	— large intestines	00·00	45·96	42·86	11·18

NOTE (27,) referred to in NOTE (7,) p. 21.

COMPOSITION OF ANIMAL ALBUMEN AND FIBRINE, AND OF THE DIFFERENT TISSUES OF THE BODY.

1. ALBUMEN.

	Scherer.*a				Jones.*b	
	From the serum of blood.			From eggs.	From yolk of egg.	
	I.	II.	III.	IV.	V.	VI.
Carbon	53·850	55·461	55·097	55·000	53·72	53·45
Hydrogen	6·983	7·201	6·880	7·073	7.55	7·66
Nitrogen	15·673	15·673	15·681	15·920	13·60	13·34
Oxygen Sulphur Phosphorus	23·494	21·655	22·342	22·007	25·13	25·55

a Ann. der Chem. und Pharm., XL., 36. *b* Ibid. 67.

	Jones.*	Scherer.*				
	From albumen of brain.	From hydrocele.	From congestive abscess.	From pus.		From fluid of dropsy
	VII.	VIII.	IX.	X.	XI.	XII
Carbon	55·50	54·921	54·757	54·663	54·101	54·302
Hydrogen	7·19	7·077	7·177	7·022	6·947	7·176
Nitrogen	16·31	15·465	15·848	15·839	15·660	15·717
Oxygen Sulphur Phosphorus	21·00	22·537	22·224	22·476	23·292	22·805

	Mulder.*a*
Carbon	54·84
Hydrogen	7·09
Nitrogen	15·83
Oxygen	21·23
Sulphur	0·68
Phosphorus	0·33

a Ann. der Pharm. XXVIII., 74.

2. FIBRINE.

	Scherer.*a						
	I.	II.	III.	IV.	V.	VI.	VII.
Carbon	53·671	54.454	55·002	54·967	53·571	54·686	54·844
Hydrogen	6·878	7·069	7·216	6·867	6·895	6·835	7·219
Nitrogen	15·763	15·762	15·817	15·913	15·720	15·720	16·065
Oxygen Sulphur Phosphorus	23·688	22·715	21·965	22·244	23·814	22·759	21·872

a Ann. der Chem. und Pharm., XL., 33.

Carbon	54·56
Hydrogen	6·90
Nitrogen	15.72
Oxygen	22·13
Sulphur	0·33
Phosphorus	0·36

a Ann. der Chem. und Pharm., XXVIII., 74.

3. GELATINOUS TISSUES.

	Scherer.*a					Calculated. $C_{48}H_{41}N_{7\frac{1}{2}}O_{18}$
	Isinglass.	Tendons of the calf's foot.			Tunica sclerotica.	
Carbon	50·557	49·563	50·960	50·774	50·995	50·207
Hydrogen	6·903	7·148	7·188	7·152	7·075	7·001
Nitrogen	18·790	18·470	18·320	18·320	18·723	18·170
Oxygen	23·750	24.819	23·532	23·754	23·207	24·622

a Ann. der Chem. und Pharm., XL., 46.

	Mulder.	
Carbon	50·048	50·048
Hydrogen	6·477	6·643
Nitrogen	18·350	18·388
Oxygen	25·125	24·921

4. TISSUES CONTAINING CHONDRINE.

	Scherer.*a			Calculated $C_{48}H_{40}N_{6}O_{20}$	Mulder.
	Cartilages of the ribs of the calf.		Cornea.		
Carbon	49·496	50·895	49·522	50·745	50·607
Hydrogen	7·133	6·962	7·097	6·904	6·578
Nitrogen	41·908	14·908	14·399	14·692	14·437
Oxygen	28·463	27·235	28·982	27·659	28·378

a Ann. der Chem. und Pharm., XL., 49.

5. COMPOSITION OF THE MIDDLE MEMBRANE OF ARTERIES.

	Scherer.*a		Calculated $C_{48}H_{38}N_{6}O_{16}$
	I.	II.	
Carbon	53·750	53·393	53·91
Hydrogen	7·079	6·973	6·96
Nitrogen	15·360	15·360	15·60
Oxygen	23·811	24·274	23·53

a Ann. der Chem. und Pharm., XL., 51.

6. COMPOSITION OF HORNY TISSUES.

	Scherer.*a						
	External skin of the sole of the foot.		Hair of the beard.	Hair of the head.			
					Fair.	Brown.	Black.
Carbon	51·036	50·752	51·529	50·652	49·345	50·622	49·935
Hydrogen	6·801	6·761	6·687	6·769	6·576	6·613	6·631
Nitrogen	17·225	17·225	17·936	17·936	17·936	17·936	17·936
Oxygen Sulphur	24·938	25·262	23·848	24·643	26·143	24·829	25·498

	Scherer.*a						Calculated $C_{48}H_{39}N_{7}O_{17}$
	Buffalo horn.				Nails.	Wool.	
Carbon	51·990	51·162	51·620	51·540	51·089	50·653	51·718
Hydrogen	6·717	6·597	6·754	6·779	6·824	7·029	6·860
Nitrogen	17·284	17·284	17·284	17·284	16·901	17·710	17·469
Oxygen Sulphur	24·009	24·957	24·342	24·397	25·186	24·608	23·953

a Ann. der Chem. und Pharm., XL., 53.

The composition of the membrane lining the interior of the shell of the egg approaches closely to that of horn. According to Scherer, it contains

	Scherer.*a
Carbon	50·674
Hydrogen	6·608
Nitrogen	16·761
Oxygen Sulphur	25·958

a Ann. der Chem. und Pharm., XL., 60.

The composition of feathers is also nearly the same as that of horn.

	Scherer.*a		Calculated $C_{48}H_{39}N_{7}O_{16}$.
	Beard of the feather.	Quill of the feather.	
Carbon	50·434	52·427	52·457
Hydrogen	7·110	7·213	6·958
Nitrogen	17·682	17·893	17·719
Oxygen	24·774	22·467	22·866

a Ann. der Chem. und Pharm., XL., 61.

The analysis here given of the beard of feathers agrees closely with that of horn, while that of the quill is more accurately represented by the attached formula, which differs from that of horn by 1 eq. of oxygen only.

7. COMPOSITION OF THE PIGMENTUM NIGRUM OCULI.

	Scherer.*a		
Carbon	58·273	58·673	57·908
Hydrogen	5·973	5·962	5·817
Nitrogen	13·768	13·768	13·768
Oxygen	21·986	21·598	22·507

a Ann. der Chem. und Pharm., XL., 63.

NOTE (28,) p. 44.

According to the analyses of Playfair and Bœckmann,

0·452 parts of dry muscular flesh gave 0·836 of carbonic acid.
0·407 . . . . 0·279 of water.
0·242 . . . . 0·450 of carb. acid and 0·164 water.
0·191 . . . . 0·360 . . . 0·130
0·305 of dried blood gave 0·575 carbonic acid and 0·202 of water.
0·214 . . . . 0·402 . . . . 0·138
1·471 of dried blood, when calcined, left 0·065 of ashes=4·42 pr. cent.
The dried flesh was found to contain of ashes 4·23 pr. cent.
The nitrogen was found to be to the carbon as 1 to 8 in equivalents.

Hence

	Flesh (beef.)		Ox-blood.		Blood.
	Playfair.	Bœckmann.	Playfair.	Bœckmann.	Mean of 2 analyses.
Carbon	51·83	51·89	51·95	51·96	51·96
Hydrogen	7·57	7·59	7·17	7·33	7·25
Nitrogen	15·01	15·05	15·07	15·08	15·07
Oxygen	21·37	21·24	21·39	21·21	21·30
Ashes	4·23	4·23	4·42	4·42	4·42

Deducting the ashes, or inorganic matter, the composition of the organic part is,

Carbon . . .	54·12	54·18	54·19	54·20
Hydrogen	7·89	7·93	7·48	7·65
Nitrogen . .	15·67	15·71	15·72	15·73
Oxygen . . .	22·32	22·18	22·31	22·12

This corresponds to the formula

C^{48}	54·62
H^{39}	7·24
N^{6}	15·81
O^{15}	22·33

NOTE (29,) p. 44.

COMPOSITION OF CHOLEIC ACID. [a]

	Demarçay.	Dumas.	Calculated $C_{76}H_{66}N_{2}O_{22}$.
Carbon . . .	63·707	63·5	63·24
Hydrogen . .	8·821	9·3	8·97
Nitrogen . . .	3·255	3·3	3·86
Oxygen . .	24.217	23·9	23·95

[a] Ann. der Pharm., XXVII., 284 and 293.

NOTE (30,) p. 44.

COMPOSITION OF TAURINE AND OF CHOLOIDIC ACID.

1. Taurine. [a]

	Demarçay.*	Dumas.	Calculated. $C_{4}H_{7}NO_{10}$
Carbon . . .	19·24	19·26	19·48
Hydrogen . .	5·78	5·66	5·57
Nitrogen . . .	11·29	11.19	11·27
Oxygen . .	63·69	63·89	63·68

[a] Ann. der Pharm., XXVII., 287 and 292.

2. Choloidic Acid. [a]

	Demarçay.*		Dumas.	Calculated. $C_{36}H_{56}O_{12}$.
	I.	II.		
Carbon . . .	73·301	73·522	73·3	74·4
Hydrogen . .	9·511	9·577	9·7	9·4
Oxygen . . .	17·188	16·901	17·0	16·2

[a] Ann. der Pharm., XXVII., 289 and 293.

In reference to the researches of Demarçay on the bile I would make the following observations.

The matter to which I have given the name of *choleic acid* is the bile itself separated from the inorganic constituents (salts, soda, &c.) which it contains. By the action of subacetate of lead aided by ammonia, all the organic constituents of the bile are made to unite with oxide of lead, with which they form an insoluble, resinous precipitate. The substance here combined with oxide of lead contains all the carbon and nitrogen of the bile. The substance which I have named *choloidic acid* is that which is obtained, when the bile, purified by alcohol from the substances insoluble in that fluid, is boiled for some time with an excess of muriatic acid. It contains all the carbon and hydrogen of the bile, except those portion which have separated in the form of taurine and ammonia. The *cholic acid* contains the elements of bile, *minus* those of carbonate of ammonia.

These three compounds, therefore, contain the products of the metamorphosis of the entire bile; their formulæ express the amount of the elements of the constituents of the bile. No one of them exists ready formed in the bile in the shape in which we obtain it; their elements are combined in a different way from that in which they were united in the bile; but the way in which these elements are arranged has not the slightest inflence on the determination by analysis of the relative proportions of the elements. In the formulæ themselves, therefore, is involved no hypothesis; they are simply expressions of the results of analysis. It signifies nothing that the choleic or choloidic acids may be composed of several compounds united together. No matter how many such they may contain, the relative proportions of all the elements taken together is expressed by the formula which is derived from the analysis.

The study of the products which are produced from the bile by the action of the atmosphere, or of chemical re-agents, may be of importance in reference to certain pathological conditions; but except as concerns the general character of the bile, the knowledge of these products is of no value to the physiologist; it is only a burthen which impedes his progress. It cannot be maintained of any one of the 38 or 40 substances, into which the bile has been divided or split up, that it exists ready formed in the healthy secretion; on the contrary, we know with certainty that most of them are mere products of the action of the re-agents which are made to act on the bile.

The bile contains soda; but it is a most remarkable and singular compound of soda. When we cause that part of the bile which dissolves in alcohol (which contains nearly all the organic part) to combine with oxide of lead, thus separating the soda, and then remove the oxide of lead, we obtain a substance, choleic acid, which, when placed in contact with soda, forms a compound similar to bile in its taste; but it is no longer bile; for bile may be mixed with organic acids, nay, even with dilute mineral acids, without becoming turbid or yielding a precipitate; while the new compound, choleate of soda, is decomposed by the feeblest acids, the whole of the choleic acid being separated. Hence, bile cannot be considered, in any sense, as choleate of soda. Further, it may be asked, in what form are the cholesterine, and stearic, and margaric acids, which are found in bile, contained in that fluid? Cholesterine is insoluble in water, and not saponifiable by alkalies; and if the two fatty acids just named were really present in the bile as soaps of soda, they would be instantly separated by other acids. Yet diluted acids cause no such separation of stearic and margaric acids in bile.

It is possible that, in the course of new and repeated investigations, the composition of the substances obtained from bile may be found different from that which has been given in our analytical developement of this subject. But this, if it should happen, can have but little effect on our formulæ; if the relative proportions of carbon and nitrogen be not changed, the differences will be confined to the proportions of oxygen and hydrogen. In that case it will be necessary for the developement of our views in formulæ, only to assume that more water and oxygen, or less water and oxygen, have taken a share in the metamorphosis of the tissues; but the truth of the developement of the process itself will not be by this means affected.

NOTE (31,) p. 44.

COMPOSITION OF CHOLIC ACID. [a]

	Dumas.	Calculated $C_{74}H_{60}O_{18}$.
Carbon	68·5	68·9
Hydrogen	9.7	9.2
Oxygen	21.8	21.9

[a] Ann. der Pharm. XXVII., 295.

NOTE (32,) p. 45.

COMPOSITION OF THE CHIEF CONSTITUENTS OF THE URINE OF MEN AND ANIMALS.

1. Uric Acid.

	Liebig.*[a]	Mitscherlich.[b]	Calculated $C_{10}H_{4}N_{4}O_{6}$.
Carbon . .	36·083	35·82	36·00
Hydrogen . .	2·441	2·38	23·6
Nitrogen . .	33·361	34·60	33.37
Oxygen . . .	28.126	27·20	28·27

[a] Ann. der Pharm., X.. 47.
[b] Poggendorff's Ann., XXXIII., 335.

2. Alloxan. *a*

A PRODUCT OF THE OXIDATION OF URIC ACID.

	Wœhler and Liebig.*		Calculated C8H4N2O10
Carbon	30·38	30·18	30·34
Hydrogen	2·57	2·48	2·47
Nitrogen	17.96	17·96	17·55
Oxygen	49·09	49·38	49.64

a Ann. der Pharm., XXVI., 260.

3. Urea.

	Prout. *a*	Wœhler and Liebig. *b*	Calculated C2H4N2O2
Carbon	19·99	20·02	20·192
Hydrogen	6·65	6·71	6·595
Nitrogen	46·65	46·73	46·782
Oxygen	26·63	26·54	26·425

a Thompson's Annals., XI., 352.
b Poggend. Ann., XX., 375.

4. Crystallized Hippuric Acid.

	Liebig.* *a*	Dumas. *b*	Mitscherlich. *c*	Calculated C18H8NO5
Carbon	60·742	60·5	60·63	60·76
Hydrogen	4·959	4·9	4·98	4·92
Nitrogen	7·816	7·7	7·90	7·82
Oxygen	26·483	26·9	26·49	26·50

a Ann. der Pharm., XII., 20.
b Ann. de Ch. et de Phys., LVII., 327.
c Poggend. Ann., XXXIII., 335.

5. Allantoine. *a*

	Wœhler and Liebig.*	Calculated C8H6N4O6
Carbon	30.60	30·66
Hydrogen	3·83	3·75
Nitrogen	35·45	35·50
Oxygen	30·12	30·09

a Ann. der Pharm., XXVI., 215.

6. Uric on Xanthic Oxide. *a*

	Wœhler and Liebig.*	Calculated C5H2N2O2.
Carbon	39·28	39·86
Hydrogen	2·95	2·60
Nitrogen	36·35	37·72
Oxygen	21·24	20·82

a Ann. der Pharm., XXVI., 344.

7. Cystic Oxide, *a*

	Thaulow.*	Calculated C6H6NO4S4.
Carbon	30·01	30·31
Hydrogen	5·10	4·94
Nitrogen	11·00	11·70
Oxygen	28·38	26·47
Su phur	25·51	26·58

a Ann der Pharm., XXVII., 200.

The cystic oxide is distinguished from all the other concretions occurring in the urinary bladder by the sulphur it contains. It can be shown with certainty, that the sulphur is present neither in the oxidized state, nor in combination with cyanogen; and in regard to its origin the remark is not without interest, that four atoms of cystic oxide contain the elements of uric acid; benzoic acid, sulphuretted hydrogen, and water; all of which are substances, the occurrence of which in the body is beyond all doubt

1 atom uric acid . . .	$C^{10}N^4H^4O^6$
1 atom benzoic acid	$C^{14}\ H^5O^3$
8 atoms sulphuretted hydrogen. . .	$H^8\ S^8$
7 atoms water	H^7O^7

4 atoms cystic oxide $= C^{24}N^4H^{24}O^{16}S^8 = 4\ (C^6NH^6O^4S^2)$.

An excellent method of detecting the presence of cystic oxide in calculi or gravel is the following:

The calculus is dissolved in a strong solution of caustic potash, and to the solution is added so much of a solution of acetate of lead, that all the oxide of lead is retained in solution. When this mixture is boiled there is formed a black precipitate of sulphuret of lead, which gives to the liquid the aspect of ink. Abundance of ammonia is also disengaged; and the alkaline fluid is found to contain, among other products, oxalic acid.

NOTE (33,) p. 45.

COMPOSITION OF OXALIC, OXALURIC, AND PARABANIC ACIDS.

1. Oxalic Acid (hydrated.)

	Gay Lussac & Thenard.	Berthollet.	Calculated C2 O3+HO
Carbon	26·566	25·13	26·66
Hydrogen	2·745	3·09	2·22
Oxygen,	70·689	71·78	71·12

2. Oxaluric Acid. *a*

	Wœhler and Liebig.*		Calculated C6H4N2O8
Carbon	27·600	27·318	27·59
Hydrogen	3·122	3·072	3·00
Nitrogen	21·218	21·218	21·29
Oxvgen	48·060	48·392	48·12

a Ann. der Pharm., XXVI., 286.

3. Parabanic Acid. *a*

	Wœhler and Liebig.*		
Carbon	31·95	31·940	31·91
Hydrogen	2·09	1·876	1·73
Nitrogen	24·66	24·650	24·62
Oxygen	41·30	41·534	41 74

a Ann. de Pharm., XXVI., 286.

NOTE (34,) p. 45.

COMPOSITION OF ROASTED FLESH.

(1.)	0·307 of flesh	gave 0·584	of carbonic acid	and 0·206	of water.
(2.)	0·255	do.	0·485	do.	0·181	do.
(3.)	0·179	do.	0·340	do.	0·125	do.

Hence—

	Flesh of roedeer (1.) Bœckmann.*	Flesh of Beef (2.) Playfair.	Flesh of veal (3.)
Carbon	52·60	52·590	42·52
Hydrogen	7·45	7·886	7·87
Nitrogen	15·23	15·214	14·70
Oxygen, Ashes	24·72	24.310	24.91

NOTE (35,) p. 46.

The formula $C^{108}H^{84}N^{18}O^{40}$, or $C^{54}H^{42}N^{9}O^{20}$, gives, when reduced to 100 parts,

C^{54}	50·07
H^{42}	6·35
N^{9}	19·32
O^{20}	24·26

Compare this with the composition of gelatine, as given in Note (27)

NOTE (37,) p. 49.

COMPOSITION OF DITHOFELLIC ACID.*a*

	Ettling and Will.*			Wœhler.*	Calculated C40H36O8
Carbon	71·19	70·80	70·23	70·83	70·83
Hydrogen	10·85	10·78	10·95	10·60	10·48
Oxygen	17·96	18·42	18·82	18·57	18·69

a Annalen der Chem. und Pharm., XXXIX., 242, and XLI., 154.

NOTE (38,) p. 56.

COMPOSITION OF SOLANINE FROM THE BUDS OF GERMINATING POTATOES. *a*

	Blanchet.
Carbon	62·11
Hydrogen	8·92
Nitrogen	1·64
Oxygen	27·33

a Ann. der Pharm., VII., 150.

NOTE (39,) p. 56.

COMPOSITION OF PICROTOXINE. *a*

	Francis.*
Carbon	60·26
Hydrogen	5·70
Nitrogen	1·30
Oxygen	32·74

a In another analysis, M. Francis obtained 0·75 per cent. of nitrogen. The picrotoxine employed for these analyses was partly obtained from the manufactory of M. Merck, in Darmstadt, and was partly prepared by M. Francis himself; it was perfectly white, and beautifully crystallized. Regnault, as is well known, found no nitrogen in this compound.

NOTE (40,) p. 56.

COMPOSITION OF QUININE.

	Liebig.*	Calculated C20H12NO2.
Carbon	75·76	74·39
Hydrogen	7·52	7·25
Nitrogen	8·11	8·52
Oxygen	8·62	9·64

NOTE (41,) p. 156.

COMPOSITION OF MORPHIA. *a*

	Liebig.*	Regnault.		Calculated C35H20NO6
Carbon	72·340	72·87	72·41	72·28
Hydrogen	6·366	6·86	6·84	6·74
Nitrogen	4·995	5·01	5·01	4·80
Oxygen	16·299	15·26	15·74	16·18

a Ann. der Pharm., XXVI., 23.

NOTE (42,) p. 156.

COMPOSITION OF CAFFEINE, THEINE, GUARANINE, THEOBROMINE, AND ASPARAGINE.

	Caffeine. *a* Pfaff and Liebig.*	Theine. *b* Jobst.	Guaranine. *c* Martius.	Calculated C8H5N2O2
Carbon	49·77	50·101	49·679	49·798
Hydrogen	5·33	5·214	5·139	5·082
Nitrogen	28·78	29·009	29·180	28·832
Oxygen	16·12	15·676	16·002	16·288

a Ann. der Pharm., I., 17. *b* Ann. der Pharm., XXV., 63. *c* Ann. der Pharm., XXVI., 95

Guaranine is the name given to the crystallized principle of the guarana officinalis, till it was shown to be identical with caffeine and theine, as the above analyses demonstrate.

COMPOSITION OF THEOBROMINE. *a*

	Woskreseusky.			Calculated C9H5N3O2
Carbon	47·21	46·97	46·71	46·43
Hydrogen	4·53	4·61	4·52	4·20
Nitrogen	35·38	35·38	35·38	35·85
Oxygen	12·88	13·04	13·39	13·51

a Ann. der Chem. und Pharm., xli., 125.

COMPOSITION OF ASPARAGINE. *a*

	Liebig.	Calculated C8H8N2O6 + 2HO
Carbon	32·351	32·35
Hydrogen	6·844	6·60
Nitrogen	18·734	18·73
Oxygen	42·021	42·32

a Ann. der Pharm., VII., 146.

ON THE CONVERSION OF BENZOIC ACID INTO HIPPURIC ACID.* BY WILHELM KELLER

(From the Annalen der Chemie und Pharmacie.)

So early as in the edition of Berzelius' "Lehrbuch der Chemie," published in 1831, Professor Wöhler had expressed the opinion, that benzoic acid, during digestion, was probably converted into hippuric acid. This opinion was founded on an experiment which he had made on the passage of benzoic acid into the urine. He found in the urine of a dog which had eaten half a drachm of benzoic acid with his food, an acid crystallizing in needle-shaped prisms, which had the general properties of benzoic acid, and which he then took for benzoic acid. (Tiedemann's Zeitschrift für Physiologie, i. 142.) These crystals were obviously hippuric acid, as plainly appears from the statements, that they had the aspect of nitre, and, when sublimed, left a residue of carbon. But at that time hippuric acid was not yet discovered; and it is well known that, till 1829, when these acids were first distinguished from each other by Liebig, it was uniformly confounded with benzoic acid.

The recently published statement of A. Ure, that he actually found hippuric acid in the urine of a patient who had taken benzoic acid, recalled this relation, so remarkable in a physiological point of view, and induced me to undertake the following experiments, which, at the suggestion of Professor Wöhler, I made on myself. The supposed conversion of benzoic acid into hippuric acid has, by these experiments, been unequivocally established.

I took, in the evening before bed-time, about thirty-two grains of pure benzoic acid in syrup. During the night I perspired strongly, which was probably an effect of the acid, as in general I am with great difficulty made to transpire profusely. I could perceive no other effect, even when, next day, I took the same dose three times; indeed, even the perspiration did not again occur.

The urine passed in the morning had an uncommonly strong acid reaction, even after it had been evaporated, and had stood for twelve hours. It deposited only the usual sediment of earthy salts. But when it was mixed with muriatic acid, and allowed to stand, there were formed in it long prismatic, brownish crystals, in great quantity, which even in this state, could not be taken for benzoic acid. Another portion, evaporated to the consistence of syrup, formed, when mixed with muriatic acid, a magma of crystalline scales. The crystalline mass was pressed, dissolved in hot water, treated with animal charcoal, and recrystallized. By this means the acid was obtained in colourless prisms, an inch in length.

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* To the evidence produced by A. Ure, of the conversion of benzoic acid into hippuric acid in the human body, M. Keller has added some very decisive proofs, which I append to this work on account of their physiological importance. The experiments of M. Keller were made in the laboratory of Professor Wöhler, at Göttingen; and they place beyond all doubt the fact that a non-azotized substance taken in the food can take a share, by means of its elements, in the act of transformation of the animal tissues, and in the formation of a secretion. This fact throws a clear light on the mode of action of the greater number of remedies; and if the influence of caffeine on the formation of urea or uric acid should admit of being demonstrated in a similar way, we shall then possess the key to the action of quinine and of the other vegetable alkalies.—J. L.

Their crystals were pure hippuric acid. When heated, they melted easily; and when exposed to a still stronger heat, the mass was carbonized, with a smell of oil of bitter almonds, while benzoic acid sublimed. To remove all doubts, I determined the proportion of carbon in the crystals, which I found to be 60·4 per cent. Crystallized hippuric acid, according to the formula $C^{18}H^{8}NO^{5} + HO$, contains 60·67 per cent. of carbon; crystallized benzoic acid, on the other hand, contains 69·10 per cent. of carbon.

As long as I continued to take benzoic acid, I was able easily to obtain hippuric acid in large quantity from the urine; and since the benzoic acid seems so devoid of any injurious effect on the health, it would be easy in this way to supply one's self with large quantities of hippuric acid. It would only be necessary to engage a person to continue for some weeks this new species of manufacture.

It was of importance to examine the urine which contained hippuric acid, in reference to the two normal chief constituents, urea and uric acid. Both were contained in it, and apparently in the same proportion as in the normal urine.

The inspissated urine, after the hippuric acid had been separated by muriatic acid yielded, on the addition of nitric acid, a large quantity of nitrate of urea. It had previously deposited a powder, the solution of which in nitric acid gave, when evaporated to dryness, the well-known purple colour characteristic of uric acid. This observation is opposed to the statement of Ure; and he is certainly too hasty in recommending benzoic acid as a remedy for the gouty and calculous concretions of uric acid. He seems to suppose that the uric acid has been employed in the conversion of benzoic acid into hippuric acid; but as his observations were made on a gouty patient, it may be supposed that the urine, even without the internal use of benzoic acid, would have been found to contain no uric acid. Finally, it is clear that the hippuric acid existed in the urine in combination with a base, because it only separated after the addition of an acid.

THE END.

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End of Volume

Volume:

3

FAMILIAR

LETTERS ON CHEMISTRY,

AND ITS RELATION TO

COMMERCE, PHYSIOLOGY, AND AGRICULTURE.

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'FIRST' AND 'SECOND SERIES,' "CHEMISTRY OF FOOD," ETC., ETC.

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PREFACE.

THE letters contained in this little Volume embrace some of the most important points of the science of Chemistry, in their application to Natural Philosophy, Physiology, Agriculture and Commerce. Some of them treat of subjects which have already been, or will hereafter be, more fully discussed in my larger works. They were intended to be mere sketches, and were written for the especial purpose of exciting the attention of governments, and an enlightened public, to the necessity of establishing Schools of chemistry, and of promoting, by every means, the study of a science so intimately connected with the arts, pursuits, and social well-being of modern civilized nations.

For my own part I do not scruple to avow the conviction, that ere long, a knowledge of the principal truth of Chemistry will be expected in every educated man, and that it will be as necessary to the Statesman and Political Economist, and the Practical Agriculturist, as it is already indispensable to the Physician and the Manufacturer.

In Germany, such of these Letters as have been already published, have not failed to produce some of the results anticipated. New professorships have been established in the Universities of Gottingen and Wurtzburg, for the express purpose of facilitating the application of chemical truths to the practical arts of life, and of following up the new line of investigation and research—the bearing of Chemistry upon Physiology, Medicine, and Agriculture,—which may be said to be only just begun.

My friend, Dr. Ernest Dieffenbach, one of my first pupils, who is well acquainted with all the branches of Chemistry, Physics, Natural History, and Medicine, suggested to me that a collection of these Letters would be acceptable to the English public, which has so favorably received my former works.

I readily acquiesced in the publication of an English edition, and undertook to write a few additional Letters, which should embrace some conclusions I have arrived at, in my recent investigations, in connexion with the application of chemical science to the physiology of plants and agriculture.

My esteemed friend, Dr. Gardner, has had the kindness to revise the manuscript and the proof-sheets for publication, for which I cannot refrain expressing my best thanks.

It only remains for me to add a hope, that this little offering may serve to make new friends to our beautiful and useful science, and be a remembrancer to those old friends who have, for many years past, taken a lively interest in all my labors.

JUSTUS LIEBIG.

Giessen, August, 1852.

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FAMILIAR LETTERS ON CHEMISTRY;

LETTER I.

MY DEAR SIR:

The influence which the science of chemistry exercises upon human industry, agriculture, and commerce; upon physiology, medicine, and other sciences, is now so interesting a topic of conversation every where, that it may be no unacceptable present to you, if I trace in a few familiar letters, some of the relations it bears to these various sciences, and exhibit for you its actual effects upon the present social condition of mankind.

In speaking of the present state of chemistry, its rise and progress; I shall need no apology, if, as a preliminary step, I call your attention to the implements which the chemist employs—the means which are indispensable to his labors and to his success.

These consist, generally, of materials furnished to us by nature, endowed with many most remarkable properties fitting them for our purposes. If one of them is a production of art, yet its adaptation to the use of mankind—the qualities which render it available to us—must be referred to the same source as those derived immediately from nature.

Cork, platinum, glass, and caoutchouc, are the substances to which I allude, and which minister so essentially to modern chemical investigations. Without them, indeed, we might have made some progress, but it would have been slow; we might have accomplished much, but it would have been far less than has been done with their aid. Some persons, by the employment of expensive substitutes, might have successfully pursued the science; but incalculably fewer minds would have been engaged in its advancement. These materials have only been duly appreciated and fully adopted within a very recent period. In the time of Lavoisier, the rich alone could make chemical researches; the necessary apparatus could only be procured at a very great expense.

And first, of glass. Every one is familiar with most of the properties of this curious substance—its transparency, hardness, destitution of color, and stability under ordinary circumstances. To these obvious qualities we may add those which especially adapt it to the use of the chemist, namely, that it is unaffected by most acids or other fluids contained within it. At certain temperatures it becomes more ductile and plastic than wax, and may be made to assume in our hands, before the flame of a common lamp, the form of every vessel we need to contain our materials, and of every apparatus required to pursue our experiments.

Then, how admirable and valuable are the properties of cork! How little do men reflect upon the inestimable worth of so common a substance! How few rightly esteem the importance of it to the progress of science, and the moral advancement of mankind! There is no production of nature or art equally adapted to the purposes to which the chemist applies it. Cork consists of a soft, highly elastic substance, as a basis, having diffused throughout a matter with properties resembling wax, tallow, and resin, yet dissimilar to all of these, and termed *suberin*. This renders it perfectly impermeable to fluids, and, in a great measure, even to gases. It is thus the fittest material we possess for closing our bottles, and retaining their contents. By its means, and with the aid of caoutchouc, we connect our vessels and tubes of glass, and construct the most complicated apparatus. We form joints and links of connexion, adapt large apertures to small, and thus dispense altogether with the aid of the brass-founder and the mechanist. Thus the implements of the chemist are cheaply and easily procured, immediately adapted to any purpose, and readily repaired or altered.

Again; in investigating the composition of solid bodies—of minerals—we are under the necessity of bringing them into a liquid state, either by solution or fusion. Now vessels of glass, of porcelain, and of all non-metallic substances, are destroyed by the means we employ for that purpose—are acted upon by many acids, by alkalies, and the alkaline carbonates. Crucibles of gold and silver would melt at high temperatures. But we have a combination of all the qualities we can desire, in platinum. This metal was only first adapted to these uses about fifty years since. It is cheaper than gold, harder and more durable than silver, infusible at all temperatures of our furnaces, and is left intact by acids and alkaline carbonates. Platinum unites all the valuable properties of gold and of porcelain, resisting the action of heat, and of almost all chemical agents.

As no mineral analysis could be made perfectly without platinum vessels, had we not possessed this metal, the composition of minerals would have yet remained unknown; without cork and caoutchouc we should have required the costly aid of the mechanician at every step. Even without the latter of these adjuncts, our instruments would have been far more costly and fragile. Possessing all these gifts of nature, we economize incalculably our time—to us more precious than money!

Such are our instruments. An equal improvement has been accomplished in our laboratory. This is no longer the damp, cold, fire-proof vault of the metallurgist, nor the manufactory of the druggist, fitted up with stills and retorts. On the contrary, a light, warm, comfortable room, where beautifully constructed lamps supply the place of furnaces, and the pure and odorous flame of gas, or of spirits of wine, supersedes coal and other fuel, and gives us all the fire we need; where health is not invaded, nor the free exercise of thought impeded; there we pursue our inquiries, and interrogate nature to reveal her secrets.

To these simple means must be added the *balance*, and then we possess every thing which is required for the most extensive researches.

The great distinction between the manner of proceeding in chemistry and natural philosophy, is, that one *weighs*, the other *measures*. The natural philosopher has applied his measures to nature for many centuries, but only for fifty years have we attempted to advance our philosophy by *weighing*.

For all great discoveries chemists are indebted to the balance—that incomparable instrument which gives permanence to every observation, dispels all ambiguity, establishes truth, detects error, and guides us in the true path of inductive science.

The balance, once adopted as a means of investigating nature, put an end to the school of Aristotle in physics. The explanation of natural phenomena by mere fanciful speculations, gave place to a true natural philosophy. Fire, air, earth, and water, could no longer be regarded as elements. Three of them could henceforth be considered only as significative of the *forms* in which all matter exists. Every thing with which we are conversant upon the surface of the earth is solid, liquid, or aeriform; but the notion of the elementary nature of air, earth, and water, so universally held, was now discovered to belong to the errors of the past.

Fire was found to be but the visible and perceptible indication of changes proceeding within the so-called elements.

Lavoisier investigated the composition of the atmosphere and of water, and studied the many wonderful offices performed by an element common to both in the scheme of nature, namely, *oxygen:* and he discovered many of the properties of this elementary gas.

After his time, the principal problem of chemical philosophers was to determine the composition of the solid matters composing the earth. To the eighteen metals previously known, were soon added, twenty-four discovered to be constituents of minerals. The great mass of the earth was shown to be composed of metals in combination with oxygen, to which they are united in one, two, or more definite and unalterable proportions, forming compounds which are termed metallic oxides, and these again, combined with oxides of other bodies, essentially different to metals, namely, carbon, and silicium. If to these we add certain compounds of sulphur with metals, in which the sulphur takes the place of oxygen, and forms sulphurets, and one other body—common salt—(which is a compound of sodium and chlorine,) we have every substance which exists in a solid form upon our globe in any very considerable mass. Other compounds, innumerably various, are found only in small scattered quantities.

The chemist, however, did not remain satisfied with the separation of minerals into their component elements, *i. e.*, their analysis; but he sought by synthesis (*i. e.*, by combining the separate elements and forming substances similar to those constructed by nature), to prove the accuracy of his processes and the correctness of his conclusions. Thus he formed, for instance, pumice-stone, feld-spar, mica, iron pyrites, &c., artificially.

But of all the achievements of inorganic chemistry the artificial formation of lapis lazuli was the most brilliant and the most conclusive. This mineral, as presented to us by nature, is calculated powerfully to arrest our attention by its beautiful azure-blue color, its remaining unchanged by exposure to air or to fire, and furnishing us with a most valuable pigment, Ultramarine, more precious than gold!

The analysis of lapis lazuli represented it to be composed of silica, alumina, and soda, three colorless bodies, with sulphur and a trace of iron. Nothing could be discovered in it of the nature of a pigment, nothing to which its blue color could be referred, the cause of which was searched for in vain. It might therefore have been supposed that the analyst was here altogether at fault, and that at any rate its artificial production must be impossible. Nevertheless, this has been accomplished, and simply by combining in the proper proportions, as determined by analysis, silica, alumina, soda, iron, and sulphur. Thousands of pounds weight are now manufactured from these ingredients, and this artificial ultramarine is as beautiful as the natural, while for the price of a single ounce of the latter we may obtain many pounds of the former.

With the production of artificial lapis lazuli, the formation of mineral bodies by synthesis ceased to be a scientific problem to the chemist; he has no longer sufficient interest in it to pursue the subject. He may now be satisfied that analysis will reveal to him the true constitution of minerals. But to the mineralogist and geologist it is still in a great measure an unexplored field, offering inquiries of the highest interest and importance to their pursuits.

After becoming acquainted with the constituent elements of all the substances within our reach, and the mutual relations of these elements, the remarkable transmutations to which bodies are subject under the influence of the vital powers of plants and animals, became the principal object of chemical investigations, and the highest point of interest. A new science, inexhaustible as life itself, is here presented us, standing upon the sound and solid foundation of a well established inorganic chemistry. Thus the progress of science is, like the development of nature's works, gradual and expansive. After the buds and branches spring forth the leaves and blossoms, after the blossoms the fruit.

Chemistry, in its application to animals and vegetables, endeavors jointly with physiology to enlighten us respecting the mysterious processes and sources of organic life.

LETTER II.

My Dear Sir:

In my former letter I reminded you that three of the supposed elements of the ancients represent the forms or state in which all the ponderable matter of our globe exists; I would now observe, that no substance possesses absolutely any one of those conditions; that modern chemistry recognises nothing unchangeably solid, liquid, or aeriform: means have been devised for effecting a change of state in almost every known substance. Platinum, alumina, and rock crystal, it is true, cannot be liquefied by the most intense heat of our furnaces, but they melt like wax before the flame of the oxy-hydrogen blowpipe. On the other hand, of the twenty-eight gaseous bodies with which we are acquainted, twenty-five may be reduced to a liquid state, and one into a solid. Probably, ere long, similar changes of condition will be extended to every form of matter.

There are many things relating to this condensation of the gases worthy of your attention. Most aeriform bodies, when subjected to compression, are made to occupy a space which diminishes in the exact ratio of the increase of the compressing force. Very generally, under a force double or triple of the ordinary atmospheric pressure they become one half or one third their former volume. This was a long time considered to be a law, and known as the law of Marriotte; but a more accurate study of the subject has demonstrated that this law is by no means of general application. The volume of certain gases does *not* decrease in the ratio of the increase of the force used to compress them, but in some, a diminution of their bulk takes place in a *far greater degree* as the pressure increases.

Again, if ammoniacal gas is reduced by a compressing force to one sixth of its volume, or carbonic acid is reduced to one thirty-sixth, a portion of them loses entirely the form of a gas, and becomes a liquid, which, when the pressure is withdrawn, assumes again in an instant its gaseous state—another deviation from the law of Marriotte.

Our process for reducing gases into fluids is of admirable simplicity. A simple bent tube, or a reduction of temperature by artificial means, have superseded the powerful compressing machines of the early experimenters.

The cyanuret of mercury, when heated in an open glass tube, is resolved into cyanogen gas and metallic mercury; if this substance is heated in a tube hermetically sealed, the decomposition occurs as before, but the gas, unable to escape, and shut up in a space several hundred times smaller than it would occupy as gas under the ordinary atmospheric pressure, becomes a fluid in that part of the tube which is kept cool.

When sulphuric acid is poured upon limestone in an open vessel, carbonic acid escapes with effervescence as a gas; but if the decomposition is effected in a strong, close, and suitable vessel of iron, we obtain the carbonic acid in the state of liquid. In this manner it may be obtained in considerable quantities, even many pounds weight. Carbonic acid is separated from other bodies with which it is combined as a fluid under a pressure of thirty-six atmospheres.

The curious properties of fluid carbonic acid are now generally known. When a small quantity is permitted to escape into the atmosphere, it assumes its gaseous state with extraordinary rapidity, and deprives the remaining fluid of caloric so rapidly that it congeals into a white crystalline mass like snow: at first, it was indeed thought to be really snow, but upon examination it proved to be pure frozen carbonic acid. This solid, contrary to expectation, exercises only a feeble pressure upon the surrounding medium. The fluid acid enclosed in a glass tube rushes at once, when opened, into a gaseous state, with an explosion which shatters the tube into fragments; but solid carbonic acid can be handled without producing any other effect than a feeling of intense cold. The particles of the carbonic acid being so closely approximated in the solid, the whole force of cohesive attraction (which in the fluid is weak) becomes exerted, and opposes its tendency to assume its gaseous state; but as it receives heat from surrounding bodies, it passes into gas gradually and without violence. The transition of solid carbonic acid into gas deprives all around it of caloric so rapidly and to so great an extent, that a degree of cold is produced immeasurably great, the greatest indeed known. Ten, twenty, or more pounds weight of mercury, brought into contact with a mixture of ether and solid carbonic acid, become in a few moments firm and malleable. This, however, cannot be accomplished without considerable danger. A melancholy accident occurred at Paris, which will probably prevent for the future the formation of solid carbonic acid in these large quantities, and deprive the next generation of the gratification of witnessing these curious experiments. Just before the commencement of the lecture in the Laboratory of the Polytechnic School, an iron cylinder, two feet and a half long and one foot in diameter, in which carbonic acid had been developed for experiment before the class, burst, and its fragments were scattered about with the most tremendous force; it cut off both the legs of the assistant and killed him on the spot. This vessel, formed of the strongest cast iron, and shaped like a cannon, had often been employed to exhibit experiments in the presence of the students. We can scarcely think, without shuddering, of the dreadful calamity such an explosion would have occasioned in a hall filled with spectators.

When we had ascertained the fact of gases becoming fluid under the influence of cold or pressure, a curious property possessed by charcoal, that of absorbing gas to the extent of many times its volume,—ten, twenty, or even, as in the case of ammoniacal gas or muriatic acid gas, eighty or ninety fold—which had been long known, no longer remained a mystery. Some gases are absorbed and condensed within the pores of the charcoal, into a space several hundred times smaller than they before occupied; and there is now no doubt they there become fluid, or assume a solid state. As in a thousand other instances, chemical action here supplants mechanical forces. *Adhesion* or heterogeneous attraction, as it is termed, acquired by this discovery a more extended meaning; it had never before been thought of as a cause of change of state in matter; but it is now evident that a gas adheres to the surface of a solid body by the same force which condenses it into a liquid.

The smallest amount of a gas—atmospheric air for instance—can be compressed into a space a thousand times smaller by mere mechanical pressure, and then its bulk must be to the least measurable surface of a solid body, as a grain of sand to a mountain. By the mere effect of mass—the force of gravity—gaseous molecules are attracted by solids and adhere to their surfaces; and when to this physical force is added the feeblest chemical affinity, the liquefiable gases cannot retain their gaseous state. The amount of air condensed by these forces upon a square inch of surface is certainly not measurable; but when a solid body, presenting several hundred square feet of surface within the space of a cubic inch, is brought into a limited volume of gas, we may understand why that volume is diminished, why all gases without exception are absorbed. A cubic inch of charcoal must have, at the lowest computation, a surface of one hundred square feet. This property of absorbing gases varies with different kinds of charcoal: it is possessed in a higher degree by those containing the most pores, that is, where the pores are finer; and in a lower degree in the more spongy kinds, that is, where the pores are larger.

In this manner every porous body—rocks, stones, the clods of the fields, &c.—imbibe air, and therefore oxygen; the smallest solid molecule is thus surrounded by its own atmosphere of condensed oxygen; and if in their vicinity other bodies exist which have an affinity for oxygen, a combination is effected. When, for instance, carbon and hydrogen are thus present, they are converted into nourishment for vegetables—into carbonic acid and water. The development of heat when air is imbibed, and the production of steam when the earth is moistened by rain, are acknowledged to be consequences of this condensation by the action of surfaces.

But the most remarkable and interesting case of this kind of action is the imbibition of oxygen by metallic platinum. This metal, when massive, is of a lustrous white color, but it may be brought, by separating it from its solutions, into so finely divided a state, that its particles no longer reflect light, and it forms a powder as black as soot. In this condition it absorbs eight hundred times its volume of oxygen gas, and this oxygen must be contained within it in a state of condensation very like that of fluid water.

When gases are thus condensed, that is, their particles made to approximate in this extraordinary manner, their properties can be palpably shown. Their chemical actions become apparent as their physical characteristic disappears. The latter consists in the continual tendency of their particles to separate from each other; and it is easy to imagine that this elasticity of gaseous bodies is the principal impediment to the operation of their chemical force; for this becomes more energetic as their particles approximate. In that state in which they exist within the pores or upon the surface of solid bodies, their repulsion ceases, and their whole chemical action is exerted. Thus combinations which oxygen cannot enter into, decompositions which it cannot effect while in the state of gas, take place with the greatest facility in the pores of platinum containing condensed oxygen. When a jet of hydrogen gas, for instance, is thrown upon spungy platinum, it combines with the oxygen condensed in the interior of the mass; at their point of contact water is formed, and as the immediate consequence heat is evolved; the platinum becomes red hot and the gas is inflamed. If we interrupt the current of the gas, the pores of the platinum become instantaneously filled again with oxygen; and the same phenomena can be repeated a second time, and so on interminably.

In finely pulverized platinum, and even in spongy platinum, we therefore possess a *perpetuum mobile*—a mechanism like a watch which runs out and winds itself up—a force which is never exhausted—competent to produce effects of the most powerful kind, and self-renewed *ad infinitum*.

Many phenomena, formerly inexplicable, are satisfactorily explained by these recently discovered properties of porous bodies. The metamorphosis of alcohol into acetic acid, by the process known as the quick vinegar manufacture, depends upon principles, at a knowledge of which we have arrived by a careful study of these properties.

LETTER III.

My Dear Sir:

The manufacture of soda from common culinary salt may be regarded as the foundation of all our modern improvements in the domestic arts; and we may take it as affording an excellent illustration of the dependence of the various branches of human industry and commerce upon each other, and their relation to chemistry.

Soda has been used from time immemorial in the manufacture of soap and glass, two chemical productions, which employ and keep in circulation an immense amount of capital. The quantity of soap consumed by a nation would be no inaccurate measure whereby to estimate its wealth and civilization. Of two countries with an equal amount of population, the wealthiest and most highly civilized will consume the greatest weight of soap. This consumption does not subserve sensual gratification, nor depend upon fashion, but upon the feeling of the beauty, comfort, and welfare, attendant upon cleanliness; and a regard to this feeling is coincident with wealth and civilization. The rich in the middle ages concealed a want of cleanliness in their clothes and persons, under a profusion of costly scents and essences, while they were more luxurious in eating and drinking, in apparel and horses. With us a want of cleanliness is equivalent to insupportable misery and misfortune.

Soap belongs to those manufactured products, the money-value of which continually disappears from circulation, and requires to be continually renewed. It is one of the few substances which are entirely consumed by use, leaving no product of any worth. Broken glass and bottles are by no means absolutely worthless; for rags we may purchase new cloth, but soap-water has no value whatever. It would be interesting to know accurately the amount of capital involved in the manufacture of soap; it is certainly as large as that employed in the coffee trade, with this important difference as respects Germany, that it is entirely derived from our own soil. France formerly imported soda from Spain, Spanish soda being of the best quality, at an annual expenditure of twenty to thirty millions of francs. During the war with England, the price of soda, and consequently of soap and glass, rose continually; and all manufactures suffered in consequence.

The present method of making soda from common salt was discovered by Le Blanc, at the end of the last century. It was a rich boon for France, and became of the highest importance during the war of Napoleon. In a very short time it was manufactured to an extraordinary extent, especially at the seat of the soap manufactories. Marseilles possessed for a time a monopoly of soda and soap. The policy of Napoleon deprived that city of the advantages derived from this great source of commerce, and thus excited the hostility of the population to his dynasty, which became favorable to the restoration of the Bourbons. A curious result of an improvement in a chemical manufacture! It was not long, however, in reaching England.

In order to prepare the soda of commerce (which is the carbonate) from common salt, it is first converted into Glauber's salt (sulphate of soda). For this purpose eighty pounds weight of concentrated sulphuric acid (oil of vitriol) are required to one hundred pounds of common salt. The duty upon salt checked, for a short time, the full advantage of this discovery; but when the government repealed the duty, and its price was reduced to its minimum, the cost of soda depended upon that of sulphuric acid.

The demand for sulphuric acid now increased to an immense extent; and, to supply it, capital was embarked abundantly, as it afforded an excellent remuneration. The origin and formation of sulphuric acid was studied most carefully; and from year to year, better, simpler, and cheaper methods for making it were discovered. With every improvement in the mode of manufacture, its price fell; and its sale increased in an equal ratio.

Sulphuric acid is now manufactured in leaden chambers, of such magnitude that they would contain the whole of an ordinary sized house. As regards the process and the apparatus, this manufacture has reached its acmé—scarcely is either susceptible of improvement. The leaden plates of which the chambers are constructed, requiring to be joined together with lead (since tin or solder would be acted on by the acid), this process was, until lately, as expensive as the plates themselves; but now, by means of the oxy-hydrogen blowpipe, the plates are cemented together at their edges, by mere fusion, without the intervention of any kind of solder.

And then, as to the process; according to theory, one hundred pounds weight of sulphur ought to produce three hundred and six pounds of sulphuric acid; in practice, three hundred pounds are actually obtained; the amount of loss is therefore too insignificant for consideration.

Again; saltpetre being indispensable in making sulphuric acid, the commercial value of that salt had formerly an important influence upon its price. It is true that one hundred pounds of saltpetre only are required to one thousand pounds of sulphur; but its cost was four times greater than an equal weight of the latter.

Travellers had observed, near the small seaport of Yquiqui, in the district of Atacama, in Peru, an efflorescence covering the ground over extensive districts. This was found to consist principally of nitrate of soda. Advantage was quickly taken of this discovery. The quantity of this valuable salt proved to be inexhaustible, as it exists in beds extending over more than 200 square miles. It was brought to England at less than half the freight of the East India saltpetre (nitrate of potassa); and as, in the chemical manufacture, neither the potash nor the soda were required, but only the nitric acid, in combination with the alkali, the soda-saltpetre of South America soon supplanted the potash-nitre of the East. The manufacture of sulphuric acid received a new impulse; its price was much diminished without injury to the manufacturer; and, with the exception of fluctuations, caused by the impediments thrown in the way of the export of sulphur from Sicily, it soon became reduced to a minimum, and remained stationary.

Potash-saltpetre is now only employed in the manufacture of gunpowder; it is no longer in demand for other purposes; and thus, if Government effect a saving of many hundred thousand pounds annually in gunpowder, this economy must be attributed to the increased manufacture of sulphuric acid.

We may form an idea of the amount of sulphuric acid consumed, when we find that 50,000 pounds weight are made by a small manufactory, and from 200,000 to 600,000 pounds by a large one, annually. This manufacture causes immense sums to flow annually into Sicily. It has introduced industry and wealth into the arid and desolate districts of Atacama. It has enabled us to obtain platina from its ores at a moderate, and yet remunerating price; since the vats employed for concentrating this acid, are constructed of this metal, and cost from 1000*l.* to 2000*l.* sterling. It leads to frequent improvements in the manufacture of glass, which continually becomes cheaper and more beautiful. It enables us to return to our fields all their potash—a most valuable and important manure—in the form of ashes, by substituting soda in the manufacture of glass and soap.

It is impossible to trace, within the compass of a letter, all the ramifications of this tissue of changes and improvements resulting from one chemical manufacture; but I must still claim your attention to a few more of its most important and immediate results. I have already told you, that in the manufacture of soda from culinary salt, it is first converted into sulphate of soda. In this first part of the process, the action of sulphuric acid produces primary muriatic acid to the extent of one and a half the amount of the sulphuric acid employed. At first, the profit upon the soda was so great that no one took the trouble to collect the muriatic acid; indeed it had no commercial value. A profitable application of it was, however, soon discovered: it is a compound of chlorine, and this substance may be obtained from it purer than from any other source. The bleaching power of chlorine has long been known; but it was only employed upon a large scale after it was obtained from residuary muriatic acid, and it was found that in combination with lime, it could be transported to distances without inconvenience. Thenceforth it was used for bleaching cotton; and, but for this new bleaching process, it would scarcely have been possible for the cotton manufacture of Great Britain to have attained its present enormous extent—it could not have competed in price with France and Germany. In the old process for bleaching, every piece must be exposed to the air and light during several weeks in the summer, and kept continually moist by manual labor. For this purpose, meadow land, suitably situated, was essential. But a single establishment, near Glasgow, bleaches 1,400 pieces of cotton daily, throughout the year. What an enormous capital would be required to purchase land for this purpose! How greatly would it increase the cost of bleaching to pay interest upon this capital, or to hire so much land in England! This expense would scarcely have been felt in Germany. Beside the diminished expense, the cotton stuffs bleached with chlorine, suffer less in the hands of skilful workmen, than those bleached in the sun; and already the peasantry in some parts of Germany have adopted it, and find it advantageous.

Another use to which cheap muriatic acid is applied, is the manufacture of glue from bones. Bone contains from 30 to 36 per cent. of earthy matter—chiefly phosphate of lime, and the remainder is gelatine. When bones are digested in muriatic acid, they become transparent and flexible like leather, the earthy matter is dissolved, and after the acid is all carefully washed away, pieces of glue, of the same shape as the bones, remain, which are soluble in hot water and adapted to all the purposes of ordinary glue, without further preparation.

Another important application of sulphuric acid may be adduced, namely, to the refining of silver, and the separation of gold, which is always present in some proportion in native silver. Silver, as it is usually obtained from mines in Europe, contains, in sixteen ounces, six to eight ounces of copper. When used by the silversmith, or in coining, sixteen ounces must contain, in Germany thirteen ounces of silver, in England about fourteen and a half. But this alloy is always made artificially, by mixing pure silver with the due proportion of the copper; and for this purpose the silver must be obtained pure by the refiner. This he formerly effected by amalgamation, or by roasting it with lead; and the cost of this process was about 2*l.* for every hundred weight of silver. In the silver so prepared, about $\frac{1}{1200}$th to $\frac{1}{2000}$th part of gold remained. To effect the separation of this by nitric hydrochloric acid was more expensive than the value of the gold; it was, therefore, left in utensils, or circulated in coin, valueless. The copper, too, of the native silver was of no use whatever. But the $\frac{1}{1000}$th part of gold, being about one and one half per cent. of the value of the silver, now covers the cost of refining, and affords an adequate profit to the refiner; so that he effects the separation of the copper, and returns to his employer the whole amount of the pure silver, as well as the copper, without demanding any payment: he is amply remunerated by that minute portion of gold. The new process of refining is a most beautiful chemical operation. The granulated metal is boiled in concentrated sulphuric acid, which dissolves both the silver and the copper, leaving the gold nearly pure, in the form of a black powder. The solution is then placed in a leaden vessel containing metallic copper; this is gradually dissolved, and the silver precipitated in a pure metallic state. The sulphate of copper is also a valuable product, being employed in the manufacture of green and blue pigments.

Other immediate results of the economical production of sulphuric acid, are the general employment of phosphorus matches, and of stearine candles—that beautiful substitute for tallow and wax. Twenty-five years ago, the present prices and extensive applications of sulphuric and muriatic acids, of soda, phosphorus, &c., would have been considered utterly impossible. Who is able to foresee what new and unthought-of chemical productions, ministering to the service and comforts of mankind, the next twenty-five years may produce?

After these remarks, you will perceive that it is no exaggeration to say, we may fairly judge of the commercial prosperity of a country from the amount of sulphuric acid it consumes. Reflecting upon the important influence which the price of sulphur exercises upon the cost of production of bleached and printed cotton stuffs, soap, glass, &c., and remembering that Great Britain supplies America, Spain, Portugal, and the East, with these, exchanging them for raw cotton, silk, wine, raisins, indigo, &c., &c., we can understand why the English Government should have resolved to resort to war with Naples, in order to abolish the sulphur monopoly, which the latter power attempted recently to establish. Nothing could be more opposed to the true interests of Sicily than such a monopoly; indeed, had it been maintained a few years, it is highly probable that sulphur, the source of her wealth, would have been rendered perfectly valueless to her. Science and industry form a power to which it is dangerous to present impediments. It was not difficult to perceive that the issue would be the entire cessation of the exportation of sulphur from Sicily. In the short period the sulphur monopoly lasted, fifteen patents were taken out for methods to obtain back the sulphuric acid used in making soda. Admitting that these fifteen experiments were not perfectly successful, there can be no doubt it would ere long have been accomplished. But then, in gypsum (sulphate of lime), and in heavy-spar (sulphate of barytes), we possess mountains of sulphuric acid; in galena (sulphate of lead), and in iron pyrites, we have no less abundance of sulphur. The problem is, how to separate the sulphuric acid, or the sulphur, from these native stores. Hundreds of thousands of pounds weight of sulphuric acid were prepared from iron pyrites, while the high price of sulphur consequent upon the monopoly lasted. We should probably ere long have triumphed over all difficulties, and have separated it from gypsum. The impulse has been given, the possibility of the process proved, and it may happen in a few years that the inconsiderate financial speculation of Naples may deprive her of that lucrative commerce. In like manner, Russia, by her prohibitory system, has lost much of her trade in tallow and potash. One country purchases only from absolute necessity from another, which excludes her own productions from her markets. Instead of the tallow and linseed oil of Russia, Great Britain now uses palm oil and cocoa-nut oil of other countries. Precisely analogous is the combination of workmen against their employers, which has led to the construction of many admirable machines for superseding manual labor. In commerce and industry every imprudence carries with it its own punishment; every oppression immediately and sensibly recoils upon the head of those from whom it emanates.

LETTER IV.

My Dear Sir:

One of the most influential causes of improvement in the social condition of mankind, is that spirit of enterprise which induces men of capital to adopt and carry out suggestions for the improvement of machinery, the creation of new articles of commerce, or the cheaper production of those already in demand; and we cannot but admire the energy with which such men devote their talents, their time, and their wealth, to realize the benefits of the discoveries and inventions of science. For even when they are expended upon objects wholly incapable of realization—nay, even when the idea which first gave the impulse proves in the end to be altogether impracticable or absurd, immediate good to the community generally ensues; some useful and perhaps unlooked for result flows directly, or springs ultimately, from exertions frustrated in their main design. Thus it is also in the pursuit of science. Theories lead to experiments and investigations; and he who investigates will scarcely ever fail of being rewarded by discoveries. It may be, indeed, the theory sought to be established is entirely unfounded in nature; but while searching in a right spirit for one thing, the inquirer may be rewarded by finding others far more valuable than those which he sought.

At the present moment, electro magnetism, as a moving power, is engaging great attention and study: wonders are expected from its application to this purpose. According to the sanguine expectations of many persons, it will shortly be employed to put into motion every kind of machinery, and among other things it will be applied to impel the carriages of railroads, and this at so small a cost, that expense will no longer be matters of consideration. England is to lose her superiority as a manufacturing country, inasmuch as her vast store of coals will no longer avail her as an economical source of motive power. "We," say the German cultivators of this science, "have cheap zinc, and, how small a quantity of this metal is required to turn a lathe, and consequently to give motion to any kind of machinery!"

Such expectations may be very attractive, and yet they are altogether illusory! they will not bear the test of many simple calculations; and this our friends have not troubled themselves to institute.

With a simple flame of spirits of wine, under a proper vessel containing boiling water, a small carriage of two hundred to three hundred pounds weight can be put into motion, or a weight of eighty to one hundred pounds may be raised to a height of twenty feet. The same effects may be produced by dissolving zinc in dilute sulphuric acid in a certain apparatus. This is certainly an astonishing and highly interesting discovery; but the question to be determined is, which of the two processes is the least expensive?

In order to answer this question, and to judge correctly of the hopes entertained from this discovery, let me remind you of what chemists denominate "equivalents." These are certain unalterable ratios of effects which are proportionate to each other, and may therefore be expressed in numbers. Thus, if we require eight pounds of oxygen to produce a certain effect, and we wish to employ chlorine for the same effect, we must employ neither more nor less than thirty-five and a half pounds weight. In the same manner, six pounds weight of coal are equivalent to thirty-two pounds weight of zinc. The numbers representing chemical equivalents express very general ratios of effects, comprehending for all bodies all the actions they are capable of producing.

If zinc be combined in a certain manner with another metal, and submitted to the action of dilute sulphuric acid, it is dissolved in the form of an oxide; it is in fact burned at the expense of the oxygen contained in fluid. A consequence of this action is the production of an electric current, which, if conducted through a wire, renders it magnetic. In thus affecting the solution of a pound weight, for example, of zinc, we obtain a definite amount of force adequate to raise a given weight one inch, and to keep it suspended; and the amount of weight it will be capable of suspending will be the greater the more rapidly the zinc is dissolved.

By alternately interrupting and renewing the contact of the zinc with the acid, and by very simple mechanical arrangements, we can give to the iron an upward and downward or a horizontal motion, thus producing the conditions essential to the motion of any machinery.

The moving force is produced by the oxidation of the zinc; and, setting aside the name given to the force in this case, we know that it can be produced in another manner. If we burn the zinc under the boiler of a steam engine, consequently in the oxygen of the air, instead of the galvanic pile, we should produce steam, and by it a certain amount of force. If we should assume (which, however, is not proved), that the quantity of force is unequal in these cases—that, for instance, we had obtained double or triple the amount in the galvanic pile, or that in this mode of generating force less loss is sustained—we must still recollect the equivalents of zinc and coal, and make these elements of our calculation. According to the experiments of Despretz, six pounds weight of zinc, in combining with oxygen, develope no more heat than one pound of coal; consequently, under equal conditions, we can produce six times the amount of force with a pound of coal as with a pound of zinc. It is therefore obvious that it would be more advantageous to employ coal instead of zinc, even if the latter produced four times as much force in a galvanic pile, as an equal weight of coal by its combustion under a boiler. Indeed it is highly probable, that if we burn under the boiler of a steam engine the quantity of coal required for smelting the zinc from its ores, we shall produce far more force than the whole of the zinc so obtained could originate in any form of apparatus whatever.

Heat, electricity, and magnetism, have a similar relation to each other as the chemical equivalents of coal, zinc, and oxygen. By a certain measure of electricity we produce a corresponding proportion of heat or of magnetic power; we obtain that electricity by chemical affinity, which in one shape produces heat, in another electricity or magnetism. A certain amount of affinity produces an equivalent of electricity in the same manner as, on the other hand, we decompose equivalents of chemical compounds by a definite measure of electricity. The magnetic force of the pile is therefore limited to the extent of the chemical affinity, and in the case before us is obtained by the combination of the zinc and sulphuric acid. In the combustion of coal, the heat results from, and is measured by, the affinity of the oxygen of the atmosphere for that substance.

It is true that, with a very small expense of zinc, we can make an iron wire a magnet capable of sustaining a thousand pounds weight of iron: let us not allow ourselves to be misled by this. Such a magnet could not raise a single pound weight of iron two inches, and therefore could not impart motion. The magnet acts like a rock, which, while at rest, presses with a weight of a thousand pounds upon a basis: it is like an enclosed lake, without an outlet and without a fall. But it may be said, we have by mechanical arrangements given it an outlet and a fall. True; and this must be regarded as a great triumph of mechanics; and I believe it is susceptible of further improvements, by which greater force may be obtained. But with every conceivable advantage of mechanism, no one will dispute that one pound of coal, under the boiler of a steam engine, will give motion to a mass several hundred times greater than a pound of zinc in the galvanic pile.

Our experience of the employment of electro-magnetism as a motory power is, however, too recent to enable us to foresee the ultimate results of contrivances to apply it; and, therefore, those who have devoted themselves to solve the problem of its application should not be discouraged, inasmuch as it would undoubtedly be a most important achievement to supersede the steam engine, and thus escape the danger of railroads, even at double their expense.

Professor Weber of Gottingen has thrown out a suggestion, that if a contrivance could be devised to enable us to convert at will the wheels of the steam carriage into magnets, we should be enabled to ascend and descend acclivities with great facility. This notion may ultimately be, to a certain extent, realized.

The employment of the galvanic pile as a motory power, however, must, like every other contrivance, depend upon the question of its relative economy: probably some time hence it may so far succeed as to be adopted in certain favorable localities; it may stand in the same relation to steam power as the manufacture of beet sugar bears to that of cane, or as the production of gas from oils and resins to that from mineral coal.

The history of beet-root sugar affords us an excellent illustration of the effect of prices upon commercial productions. This branch of industry seems at length, as to its processes, to be perfected. The most beautiful white sugar is now manufactured from the beet-root, in the place of the treacle-like sugar, having the taste of the root, which was first obtained; and instead of 3 or 4 per cent., the proportion obtained by Achard, double or even treble that amount is now produced. And notwithstanding the perfection of the manufacture, it is probable it will ere long be in most places entirely discontinued. In the years 1824 to 1827, the prices of agricultural produce were much lower than at present, while the price of sugar was the same. At one time one malter* of wheat was 10*s.*, and one klafter† of wood 18*s.*, and land was falling in price. Thus, food and fuel were cheap, and the demand for sugar unlimited; it was, therefore, advantageous to grow beet-root, and to dispose of the produce of land as sugar. All these circumstances are now different. A malter of wheat costs 18*s.*; a klafter of wood 30*s.* to 36*s.* Wages have risen, but not in proportion, while the price of colonial sugar has fallen. Within the limits of the German commercial league, as for instance, at Frankfort-on-the-Maine, a pound of the whitest and best loaf sugar is 7*d.*; the import duty is 3⅔*d.* or 30*s.* per cwt., leaving 3⅓*d.* as the price of the sugar. In the year, 1827, then, one malter of wheat was equal to forty pounds weight of sugar, while at present that quantity of wheat is worth seventy pounds of sugar. If indeed fuel were the same in price as formerly, and seventy pounds of sugar could be obtained from the same quantity of the root as then yielded forty pounds, it might still be advantageously produced; but the amount, if now obtained by the most approved methods of extraction, falls far short of this: and as fuel is double the price, and labor dearer, it follows that, at present, it is far more advantageous to cultivate wheat and to purchase sugar.

There are, however, other elements which must enter into our calculations; but these serve to confirm our conclusions, that the manufacture of beet-root sugar, as a commercial speculation, must cease. The leaves and residue of the root, after the juice was expressed, were used as food for cattle, and their value naturally increased with the price of grain. By the process formerly pursued, seventy-five pounds of juice were obtained from one hundred pounds of beet-root, and gave five pounds of sugar. The method of Schützenbach, which was eagerly adopted by the manufacturers, produced from the same quantity of root eight pounds of sugar; but it was attended with more expense to produce, and the loss of the residue as food for cattle. The increased expense in this process arises from the larger quantity of fuel required to evaporate the water; for, instead of merely evaporating the juice, the dry residue is treated with water, and we require fuel sufficient to evaporate one hundred and six pounds of fluid instead of seventy-five pounds, and the residue is only fit for manure. The additional three pounds of sugar are purchased at the expense of much fuel, and the loss of the residue as an article of food.

If the valley of the Rhine possessed mines of diamonds, as rich as those of Golconda, Visiapoor, or the Brazils, they would probably not be worth the working: at those places the cost of extraction is 28*s.* to 30*s.* the carat. With us it amounts to three or four times as much—to more, in fact, than diamonds are worth in the market. The sand of the Rhine contains gold; and in the Grand Duchy of Baden many persons are occupied in gold washing when wages are low; but as soon as they rise, this employment ceases. The manufacture of sugar from beet-root, in like manner, twelve to fourteen years ago, offered advantages which are now lost: instead, therefore, of maintaining it at a great sacrifice, it would be more reasonable, more in accordance with true natural economy, to cultivate other and more valuable productions, and with them purchase sugar. Not only would the state be a gainer, but every member of the community. This argument does not apply, perhaps, to France and Bohemia, where the prices of fuel and of colonial sugar are very different to those in Germany.

The manufacture of gas for lighting, from coals, resin, and oils, stands with us on the same barren ground.

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* Malter—a measure containing several bushels, but varying in different countries.

† Klafter—a cord, a stack, measuring six feet every way.

The materials from which gas is manufactured in England bears a direct proportion to the price of corn; there the prices of tallow and oil are twice as great as in Germany, but iron and coal are two thirds cheaper; and even in England the manufacture of gas is only advantageous when the other products of the distillation of coal, the coke, &c., can be sold.

It would certainly be esteemed one of the greatest discoveries of the age if any one could succeed in condensing coal gas into a white, dry, solid, odorless substance, portable, and capable of being placed upon a candlestick, and burned in a lamp. Wax, tallow, and oil, are combustible gases in a solid or fluid form, which offer many advantages for lighting, not performed by gas: they furnish, in well-constructed lamps, as much light, without requiring the expensive apparatus necessary for the combustion of gas, and they are generally more economical. In large towns, or such establishments as hotels, where coke is in demand, and where losses in stolen tallow or oil must be considered, together with the labor in snuffing candles and cleaning lamps, the higher price of gas is compensated. In places where gas can be manufactured from resin, oil of turpentine, and other cheap oil, as at Frankfort, this is advantageous so long as it is pursued on a small scale only. If large towns were lighted in the same manner, the materials would rise in price: the whole amount at present produced would scarcely suffice for two such towns as Berlin and Munich. But no just calculation can be made from the present prices of turpentine, resin, &c., which are not produced upon any large scale.

LETTER V.

My Dear Sir:

Until very recently it was supposed that the physical qualities of bodies, that is, hardness, color, density, transparency, &c., and still more their chemical properties, must depend upon the nature of their elements, or upon their composition. It was tacitly received as a principle, that two bodies containing the same elements in the same proportion, must of necessity possess the same properties. We could not imagine an exact identity of composition, giving rise to two bodies entirely different in their sensible appearance and chemical relations. The most ingenious philosophers entertained the opinion that chemical combination is an inter-penetration of the particles of different kinds of matter, and that all matter is susceptible of infinite division. This has proved to be altogether a mistake. If matter were infinitely divisible in this sense, its particles must be imponderable, and a million of such molecules could not weigh more than an infinitely small one. But the particles of that imponderable matter, which, striking upon the retina, gives us the sensation of light, are not in a mathematical sense infinitely small.

Inter-penetration of elements in the production of a chemical compound, supposes two distinct bodies, A and B, to occupy one and the same space at the same time. If this were so, different properties could not exist with an equal and identical composition.

That hypothesis, however, has shared the fate of innumerable imaginative explanations of natural phenomena, in which our predecessors indulged. They have now no advocate. The force of truth dependent upon observation is irresistible. A great many substances have been discovered among organic bodies, composed of the same elements in the same relative proportions, and yet exhibiting physical and chemical properties perfectly distinct one from another. To such substances the term *Isomeric* (from *ισος equal* and *μερος part*) is applied. A great class of bodies, known as the volatile oils, oils of turpentine, essence of lemons, oil of balsam, of copaiba, oil of rosemary, oil of juniper, and many others, differing widely from each other in their odor, in their medicinal effects, in their boiling point, in their specific gravity, &c., are exactly identical in composition,—they contain the same elements, carbon and hydrogen, in the same proportions.

How admirably simple does the chemistry of organic nature present itself to us from this point of view. An extraordinary variety of compound bodies produced with equal weights of two elements! and how wide their dissimilarity! The crystallised part of the oil of roses, the delicious fragrance of which is so well known, a solid at ordinary temperatures, although readily volatile, is a compound body containing exactly the same elements, and in the same proportion as the gas we employ for lighting our streets; and, in short, the same elements, in the same relative quantities, are found in a dozen other compounds, all differing essentially in their physical and chemical properties.

These remarkable truths, so highly important in their applications, were not received and admitted as sufficiently established, without abundant proofs. Many examples have long been known where the analysis of two different bodies gave the same composition; but such cases were regarded as doubtful: at any rate, they were isolated observations, homeless in the realms of science, until, at length, examples were discovered of two or more bodies, whose absolute identity of composition, with totally distinct properties, could be demonstrated in a more obvious and conclusive manner than by mere analysis; that is, they can be converted and reconverted into each other without addition and without subtraction.

In cyanuric acid, hydrated cyanic acid, and cyamelide, we have three such isomeric compounds.

Cyanuric acid is crystalline, soluble in water and capable of forming salts with metallic oxides.

Hydrated cyanic acid is a volatile and highly blistering fluid, which cannot be brought into contact with water, without being instantaneously decomposed.

Cyamelide is a white substance very like porcelain, absolutely insoluble in water.

Now, if we place the first,—cyanuric acid,—in a vessel hermetically sealed, and apply a high degree of heat, it is converted by its influence into hydratic cyanic acid; and, then, if this is kept for some time at the common temperature, it passes into cyamelide, no other element being present. And again inversely, cyamelide can be converted into cyanuric acid and hydrated cyanic acid.

We have three other bodies which pass through similar changes, in aldehyde, metaldehyde, and eltaldehyde; and, again two, in urea and cyanuret of ammonia. Further, one hundred parts of aldehyde hydrated butyric acid and acetic ether contain the same elements in the same proportion. Thus one substance may be converted into another without addition or subtraction, and without the participation of any foreign bodies in the change.

The doctrine that matter is not infinitely divisible, but on the contrary, consists of atoms incapable of further division, alone furnishes us with a satisfactory explanation of these phenomena. In chemical combinations, the ultimate atoms of bodies do not penetrate each other, they are only arranged side by side in a certain order, and the properties of the compound depend entirely upon this order. If they are made to change their place—their mode of arrangement—by an impulse from without, they combine again in a different manner, and another compound is formed with totally different properties. We may suppose that one atom combines with one atom of another element to form a compound atom, while in other bodies, two and two, four and four, eight and eight, are united; so that in all such compounds the amount per cent. of the elements is absolutely equal; and yet their physical and chemical properties must be totally different, the constitution of each atom being peculiar, in one body consisting of two, in another of four, in the third of eight, and in a fourth of sixteen simple atoms.

The discovery of these facts immediately led to many most beautiful and interesting results; they furnished us with a satisfactory explanation of observations which were before veiled in mystery—a key to many of nature's most curious recesses.

Again, solid bodies, whether simple or compound, are capable of existing in two states, which are known by the terms *amorphous* and *crystalline*.

When matter is passing from a gaseous or liquid state slowly into a solid, an incessant motion is observed, as if the molecules were minute magnets: they are seen to repel each other in one direction, and to attract and cohere together in another and in the end become arranged into a regular form, which, under equal circumstances, is always the same for any given kind of matter: that is, crystals are formed.

Time and freedom of motion for the particles of bodies are necessary to the formation of crystals. If we force a fluid or a gas to become suddenly solid, leaving no time for its particles to arrange themselves, and cohere in that direction in which the cohesive attraction is strongest, no crystals will be formed, but the resulting solid will have a different color, a different degree of hardness and cohesion, and will retract light differently; in one word, will be *amorphous*. Thus we have cinnabar as a red and a jet-black substance; sulphur a fixed and brittle body, and soft, semi-transparent and ductile; glass as a milk-white opaque substance, so hard that it strikes fire with steel, and in its ordinary and well-known state. These dissimilar states and properties of the same body are occasioned in one case by a regular, in the other by an irregular arrangement of its atoms: one is crystalline, the other amorphous.

Applying these facts to natural productions, we have reason to believe that clay-slate and many kinds of greywacke are amorphous feldspar, as transition limestone is amorphous marble, basalt and lava mixtures of amorphous zeolite and augite. Any thing that influences the cohesion, must also in a certain degree alter the properties of bodies. Carbonate of lime, if crystallized at ordinary temperatures, possesses the crystalline form, hardness, and refracting power of common spar; if crystallized at a higher temperature, it has the form and properties of arragonite.

Finally. *Isomorphism*, or the equality of form of many chemical compounds having a different composition, tends to prove that matter consists of atoms the mere arrangement of which produces all the properties of bodies. But when we find that a *different arrangement* of the *same* elements gives rise to *various* physicial and chemical properties, and a *similar arrangement* of *different* elements produces properties very much the *same*, may we not inquire whether some of those bodies which we regard as elements may not be merely modifications of the same substance? whether they are not the same matter in a different state of arrangement? We know, in fact, the existence of iron in two states, so dissimilar, that in the one, it is to the electric chain like platinum, and in the other it is like zinc; so that powerful galvanic machines have been constructed of this one metal.

Among the elements are several instances of remarkable similarity of properties. Thus there is a strong resemblance between platinum and iridium; bromine and iodine; iron, manganese and magnesium; cobalt and nickel, phosphorus and arsenic; but this resemblance consists mainly in their forming isomorphous compounds in which these elements exist in the same relative proportion. These compounds are similar, because the atoms of which they are composed are arranged in the same manner. The converse of this is also true: nitrate of stroutia becomes quite dissimilar to its common state if a certain proportion of water is taken into its composition.

If we suppose selenium to be merely modified sulphur and phosphorus, modified arsenic, how does it happen, we must inquire, that sulphuric acid and selenic acid, phosphoric and arsenic acid, respectively form compounds which it is impossible to distinguish by their form and solubility? Were these merely isomeric they ought to exhibit properties quite dissimilar!

We have not, I believe, at present the remotest ground to suppose that any one of those substances which chemists regard as elements, can be converted into another. Such a conversion, indeed, would presuppose that the element was composed of two or more ingredients, and was, in fact, not an element; and until the decomposition of these bodies is accomplished, and their constituents discovered, all pretensions to such conversions deserve no notice.

Mr. Brown, of Edinburgh, thought he had converted iron into rhodium, and carbon or paracyanogen into silicon. His paper upon this subject was published in the Transactions of the Royal Society of Edinburgh, and contained internal evidence, without a repitition of his experiments, that he was totally unacquainted with the principles of chemical analysis. But his experiments have been carefully repeated by qualified persons, and they have completely proved his ignorance; *his* rhodium is iron; and *his* silicon an impure incombustible coal.

LETTER VI.

My Dear Sir:

One of the most remarkable effects of the recent progress of science is the alliance of chemistry with physiology, by which a new and unexpected light has been thrown upon the vital processes of plants and animals. We have now no longer any difficulty in understanding the different actions of aliments, poisons, and remedial agents—we have a clear conception of the causes of hunger, of the exact nature of death; and we are not, as formerly, obliged to content ourselves with a mere description of their symptoms. It is now ascertained with positive certainty, that all the substances which constitute the food of man must be divided into two great classes, one of which serves for the nutrition and reproduction of the animal body, while the other ministers to quite different purposes. Thus starch, gum, sugar, beer, wine, spirits, &c., furnish no element capable of entering into the composition of blood, muscular fibre, or any part which is the seat of the vital principle. It must surely be universally interesting to trace the great change our views have undergone upon these subjects, as well as to become acquainted with the researches from which our present knowledge is derived.

The primary conditions of the maintenance of animal life, are a constant supply of certain matters, animal food, and of oxygen, in the shape of atmospheric air. During every moment of life, oxygen is absorbed from the atmosphere in the organs of respiration, and the act of breathing cannot cease while life continues.

The observations of physiologists have demonstrated that the body of an adult man supplied abundantly with food, neither increases nor diminishes in weight during twenty-four hours, and yet the quantity of oxygen absorbed into his system, in that period, is very considerable. According to the experiments of Lavoisier, an adult man takes into his system from the atmosphere, in one year, no less than seven hundred and forty-six pounds weight of oxygen; the calculations of Menzies make the quantity amount even to eight hundred and thirty-seven pounds; but we find his weight at the end of the year either exactly the same, or differing one way or other by at most a few pounds. What, it may be asked, has become of the enormous amount of oxygen thus introduced into the human system in the course of one year? We can answer this question satisfactorily. No part of the oxygen remains in the body, but is given out again, combined with carbon and hydrogen. The carbon and hydrogen of certain parts of the animal body combine with the oxygen introduced through the lungs and skin, and pass off in the forms of carbonic acid and vapor of water. At every expiration and every moment of life, a certain amount of its elements are separated from the animal organism, having entered into combination with the oxygen of the atmosphere.

In order to obtain a basis for an approximate calculation, we may assume, with Lavoisier and Seguin, that an adult man absorbs into his system 32½ ounces of oxygen daily—that is, 46,037 cubic inches = 15,661 grains, French weight; and further, that the weight of the whole mass of his blood is twenty-four pounds, of which eighty per cent. is water. Now, from the known composition of the blood, we know that in order to convert its whole amount of carbon and hydrogen into carbonic acid and water 64.102 grains of oxygen are required. This quantity will be taken into the system in four days and five hours. Whether the oxygen enters into combination directly with the elements of the blood, or with the carbon and hydrogen of other parts of the body, it follows inevitably—the weight of the body remaining unchanged, and in a normal condition—that as much of these elements as will suffice to supply twenty-four pounds of blood, must be taken into the system in four days and five hours; and this necessary amount is furnished by the food.

We have not, however, remained satisfied with mere approximation: we have determined accurately, in certain cases, the quantity of carbon taken daily in the food, and of that which passes out of the body in the fæces and urine combined—that is, uncombined with oxygen; and from these investigations it appears that an adult man, taking moderate exercise, consumes 13.910 ounces of carbon, which pass off through the skin and lungs as carbonic acid gas.*

It requires thirty-seven ounces of oxygen to convert 13.910 of carbon into carbonic acid. Again: according to the analysis of Boussingault (Annales de Chim. et de Phys. lxx. i., p. 136,) a horse consumes 79.110 ounces of carbon in twenty-four hours, a milch cow 70¾ ounces; so that the horse requires 13 pounds 3½ ounces, and the cow 11 pounds 10¾ ounces of oxygen.†

As no part of the oxygen taken into the system of an animal is given off in any other form than combined with carbon or hydrogen, and as in a normal condition, or state of health, the carbon and hydrogen so given off, are replaced by those elements in the food, it is evident that the amount of nourishment required by an animal for its support, must be in a direct ratio with the quantity of oxygen taken into its system. Two animals, which in equal times take up by means of the lungs and skin unequal quantities of oxygen, consume an amount of food unequal in the same ratio. The consumption of oxygen in a given time may be expressed by the number of respirations; it is, therefore, obvious, that in the same animal the quantity of nourishment required must vary with the force and number of respirations. A child breathes quicker than an adult, and, consequently, requires food more frequently, and proportionably in larger quantity, and bears hunger less easily. A bird, deprived of food, dies on the third day, while a serpent, confined under a bell, respires so slowly, that the quantity of carbonic acid generated in an hour can scarcely be observed, and it will live three months, or longer, without food. The number of respirations is fewer in a state of rest than during labor or exercise; the quantity of food necessary in both cases must be in the same ratio. An excess of food, a want of a due amount of respired oxygen, or of exercise, as also of great exercise, (which obliges us to take an increased supply of food,) together with weak organs of digestion, are incompatible with health.

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* This account is deduced from observations made upon the average daily consumption of about thirty soldiers in barracks. The food of these men, consisting of meat, bread, potatoes, lentiles, peas, beans, butter, salt, pepper, &c., was accurately weighed during a month, and each article subjected to ultimate analysis. Of the quantity of food, beer, and spirits, taken by the men when out of barracks, we have a close approximation from the report of the sergeant; and from the weight and analysis of the fæces and urine, it appears that the carbon which passes off through these channels may be considered equivalent to the amount taken in that portion of the food, and of sour-crout, which was not included in the estimate.

† 16 ounces = ½ kilogramme.

But the quantity of oxygen received by an animal through the lungs, not only depends upon the number of respirations, but also upon the temperature of the respired air. The size of the thorax of an animal is unchangeable; we may, therefore, regard the volume of air which enters at every inspiration as uniform. But its weight, and consequently the amount of oxygen it contains, is not constant. Air is expanded by heat, and contracted by cold—an equal volume of hot and cold air contains, therefore, an unequal amount of oxygen. In summer, atmospheric air contains water in the form of vapor; it is nearly deprived of it in winter. The volume of oxygen in the same volume of air is smaller in summer than in winter. In summer and winter, at the pole and at the equator, we inspire an equal volume of air; the cold air is warmed during respiration, and acquires the temperature of the body. In order, therefore, to introduce into the lungs a given amount of oxygen, less expenditure of force is necessary in winter than in summer, and for the same expenditure of force more oxygen is inspired in winter. It is also obvious that, in an equal number of respirations, we consume more oxygen at the level of the sea than on a mountain.

The oxygen, taken into the system, is given out again in the same form, both in summer and winter; we expire more carbon at a low than at a high temperature, and require more or less carbon in our food in the same proportion; and consequently more is respired in Sweden than in Sicily, and in our own country an eighth more in winter than in summer. Even if an equal weight of food is consumed in hot and cold climates, Infinite Wisdom has ordained that very unequal proportions of carbon shall be taken in it. The food prepared for the inhabitants of southern climes does not contain in a fresh state more than twelve per cent. of carbon, while the blubber and train oil, which feed the inhabitants of polar regions, contain sixty-six to eighty per cent of that element.

From the same cause it is comparatively easy to be temperate in warm climates, or to bear hunger for a long time under the equator; but cold and hunger united very soon produce exhaustion.

The oxygen of the atmosphere received into the blood in the lungs, and circulated throughout every part of the animal body, acting upon the elements of the food, is the source of *animal heat.*

LETTER VII.

MY DEAR SIR:

The source of animal heat, its laws, and the influence it exerts upon the functions of the animal body, constitute a curious and highly interesting subject, to which I would now direct your attention.

All living creatures, whose existence depends upon the absorption of oxygen, possess within themselves a source of heat, independent of surrounding objects.

This general truth applies to all animals, and extends to the seed of plants in the act of germination, to flower-buds when developing, and fruits during their maturation.

In the animal body, heat is produced only in those parts to which arterial blood, and with it the oxygen absorbed in respiration, is conveyed. Hair, wool, and feathers, receive no arterial blood, and therefore, in them no heat is developed. The combination of a combustible substance with oxygen is, under all circumstances, the only source of animal heat. In whatever way carbon may combine with oxygen, the act of combination is accompanied by the disengagement of heat. It is indifferent whether this combination takes place rapidly or slowly, at a high or at a low temperature; the amount of heat liberated is a constant quantity.

The carbon of the food being converted into carbonic acid within the body, must give out exactly as much heat as if it had been directly burnt in oxygen gas, or in common air; the only difference is, the production of the heat is diffused over unequal times. In oxygen gas the combustion of carbon is rapid, and the heat intense; in atmospheric air it burns slower, and for a longer time, the temperature being lower; in the animal body the combination is still more gradual, and the heat is lower in proportion.

It is obvious that the amount of heat liberated must increase or diminish with the quantity of oxygen introduced in equal times by respiration. Those animals, therefore, which respire frequently, and consequently consume much oxygen, possess a higher temperature than others, which, with a body of equal size to be heated, take into the system less oxygen. The temperature of a child (102°) is higher than that of an adult (99.5°). That of birds (104° to 105.4°), is higher than that of quadrupeds (98.5° to 100.4°), or that of fishes, or amphibia, whose proper temperature is from 2.7° to 3.6° higher than that of the medium in which they live. All animals, strictly speaking, are warm-blooded; but in those only which possess lungs is the temperature of the body quite independent of the surrounding medium.

The most trustworthy observations prove that in all climates, in the temperate zones, as well as at the equator or the poles, the temperature of the body in man, and in what are commonly called warm-blooded animals, is invariably the same; yet how different are the circumstances under which they live!

The animal body is a heated mass, which bears the same relations to surrounding objects as any other heated mass. It receives heat when the surrounding objects are hotter, it loses heat when they are colder than itself.

We know that the rapidity of cooling increases with the difference between the temperature of the heated body and that of the surrounding medium; that is, the colder the surrounding medium the shorter the time required for the cooling of the heated body.

How unequal, then, must be the loss of heat in a man at Palermo, where the external temperature is nearly equal to that of the body, and in the polar regions, where the external temperature is from seventy to ninety degrees lower!

Yet, notwithstanding this extremely unequal loss of heat, experience has shown that the blood of the inhabitant of the arctic circle has a temperature as high as that of the native of the south, who lives in so different a medium.

This fact, when its true significance is perceived, proves that the heat given off to the surrounding medium is restored within the body with great rapidity. This compensation must, consequently, take place more rapidly in winter than in summer, at the pole than at the equator.

Now, in different climates the quantity of oxygen introduced into the system by respiration, as has been already shown, varies according to the temperature of the external air; the quantity of inspired oxygen increases with the loss of heat by external cooling; and the quantity of carbon or hydrogen necessary to combine with this oxygen must be increased in the same ratio.

It is evident that the supply of the heat lost by cooling is effected by the mutual action of the elements of the food and the inspired oxygen, which combine together. To make use of a familiar, but not on that account a less just illustration, the animal body acts, in this respect, as a furnace, which we supply with fuel. It signifies nothing what intermediate forms food may assume, what changes it may undergo in the body, the last change is uniformly the conversion of its carbon into carbonic acid, and of its hydrogen into water. The unassimilated nitrogen of the food, along with the unburned or unoxidized carbon, is expelled in the urine or in the solid excrements. In order to keep up in the furnace a constant temperature, we must vary the supply of fuel according to the external temperature, that is, according to the supply of oxygen.

In the animal body the food is the fuel; with a proper supply of oxygen we obtain the heat given out during its oxidation or combustion. In winter, when we take exercise in a cold atmosphere, and when consequently the amount of inspired oxygen increases, the necessity for food containing carbon and hydrogen increases in the same ratio; and by gratifying the appetite thus excited, we obtain the most efficient protection against the most piercing cold. A starving man is soon frozen to death. The animals of prey in the arctic regions, as every one knows, far exceed in voracity those of the torrid zone.

In cold and temperate climates, the air, which incessantly strives to consume the body, urges man to laborious efforts in order to furnish the means of resistance to its action, while, in hot climates, the necessity of labor to provide food is far less urgent.

Our clothing is merely an equivalent for a certain amount of food. The more warmly we are clothed the less urgent becomes the appetite for food, because the loss of heat by cooling, and consequently the amount of heat to be supplied by the food, is diminished.

If we were to go naked, like certain savage tribes, or if in hunting or fishing we were exposed to the same degree of cold as the Samoyedes, we should be able with ease to consume ten pounds of flesh, and perhaps a dozen of tallow candles into the bargain, daily, as warmly clad travellers have related with astonishment of these people. We should then also be able to take the same quantity of brandy or train oil without bad effects, because the carbon and hydrogen of these substances would only suffice to keep up the equilibrium between the external temperature and that of our bodies.

According to the preceding expositions, the quantity of food is regulated by the number of respirations, by the temperature of the air, and by the amount of heat given off to the surrounding medium.

No isolated fact, apparently opposed to this statement, can affect the truth of this natural law. Without temporary or permanent injury to health, the Neapolitan cannot take more carbon and hydrogen in the shape of food than he expires as carbonic acid and water; and the Esquimaux cannot expire more carbon and hydrogen than he takes into the system as food, unless in a state of disease or of starvation. Let us examine these states a little more closely.

The Englishman in Jamaica perceives with regret the disappearance of his appetite, previously a source of frequently recurring enjoyment; and he succeeds by the use of cayenne pepper and the most powerful stimulants, in enabling himself to take as much food as he was accustomed to eat at home. But the whole of the carbon thus introduced into the system is not consumed; the temperature of the air is too high, and the oppressive heat does not allow him to increase the number of respirations by active exercise, and thus to proportion the waste to the amount of food taken; disease of some kind, therefore, ensues.

On the other hand, England sends her sick to southern regions, where the amount of the oxygen inspired is diminished in a very large proportion. Those whose diseased digestive organs have in a greater or less degree lost the power of bringing the food into the state best adapted for oxidation, and therefore are less able to resist the oxidising influence of the atmosphere of their native climate, obtain a great improvement in health. The diseased organs of digestion have power to place the diminished amount of food in equilibrium with the inspired oxygen, in the mild climate; while in a colder region the organs of respiration themselves would have been consumed in furnishing the necessary resistance to the action of the atmospheric oxygen.

In our climate, hepatic diseases, or those arising from excess of carbon, prevail in summer; in winter, pulmonary diseases, or those arising from excess of oxygen, are more frequent.

The cooling of the body, by whatever cause it may be produced, increases the amount of food necessary. The mere exposure to the open air, in a carriage or on the deck of a ship, by increasing radiation and vaporisation, increases the loss of heat, and compels us to eat more than usual. The same is true of those who are accustomed to drink large quantities of cold water, which is given off at the temperature of the body, 98.5 degrees. It increases the appetite, and persons of weak constitution find it necessary, by continued exercise, to supply to the system the oxygen required to restore the heat abstracted by the cold water. Loud and long continued speaking, the crying of infants, moist air, all exert a decided and appreciable influence on the amount of food which is taken.

We have assumed that it is especially carbon and hydrogen which, by combining with oxygen, serve to produce animal heat. In fact, observation proves that the hydrogen of the food plays a not less important part than the carbon.

The whole process of respiration appears most clearly developed, when we consider the state of a man, or other animal, totally deprived of food.

The first effect of starvation is the disappearance of fat, and this fat cannot be traced either in the urine or in the scanty fæces. Its carbon and hydrogen have been given off through the skin and lungs in the form of oxidized products; it is obvious that they have served to support respiration.

In the case of a starving man, 32¼ ounces of oxygen enter the system daily, and are given out again in combination with a part of his body. Currie mentions the case of an individual who was unable to swallow, and whose body lost one hundred pounds in weight during a month; and, according to Martell (Trans. Linn. Soc., vol. xi., p. 411), a fat pig, overwhelmed in a slip of earth, lived one hundred and sixty days without food, and was found to have diminished in weight, in that time, more than one hundred and twenty pounds. The whole history of hybernating animals, and the well established facts of the periodical accumulation, in various animals, of fat, which, at other periods, entirely disappears, prove that the oxygen, in the respiratory process, consumes, without exception, all such substances as are capable of entering into combination with it. It combines with whatever is presented to it; and the deficiency of hydrogen is the only reason why carbonic acid is the chief product; for, at the temperature of the body, the affinity of hydrogen for oxygen far surpasses that of carbon for the same element.

We know, in fact, that the graminivora expire a volume of carbonic acid equal to that of the oxygen inspired, while the carnivora, the only class of animals whose food contains fat, inspire more oxygen than is equal in volume to the carbonic acid expired. Exact experiments have shown, that in many cases only half the volume of oxygen is expired in the form of carbonic acid. These observations cannot be gainsaid, and are far more convincing than those arbitrary and artificially produced phenomena, sometimes called experiments; experiments which, made as too often they are, without regard to the necessary and natural conditions, possess no value, and may be entirely dispensed with; especially when, as in the present case, nature affords the opportunity for observation, and when we make a rational use of that opportunity.

In the progress of starvation, however, it is not only the fat which disappears, but also, by degrees, all such of the solids as are capable of being dissolved. In the wasted bodies of those who have suffered starvation, the muscles are shrunk and unnaturally soft, and have lost their contractility; all those parts of the body which were capable of entering into the state of motion have served to protect the remainder of the frame from the destructive influence of the atmosphere. Toward the end, the particles of the brain begin to undergo the process of oxidation, and delirium, mania, and death close the scene; that is to say, all resistance to the oxidizing power of the atmospheric oxygen ceases, and the chemical process of eremacausis, or decay, commences, in which every part of the body, the bones excepted, enters into combination with oxygen.

The time which is required to cause death by starvation depends on the amount of fat in the body, on the degree of exercise, as in labor or exertion of any kind, on the temperature of the air, and finally, on the presence or absence of water. Through the skin and lungs there escapes a certain quantity of water, and as the presence of water is essential to the continuance of the vital motions, its dissipation hastens death. Cases have occurred, in which a full supply of water being accessible to the sufferer, death has not occurred till after the lapse of twenty days. In one case, life was sustained in this way for the period of sixty days.

In all chronic diseases death is produced by the same cause, namely, the chemical action of the atmosphere. When those substances are wanting, whose function in the organism is to support the process of respiration; when the diseased organs are incapable of performing their proper function of producing these substances; when they have lost the power of transforming the food into that shape in which it may, by entering into combination with the oxygen of the air, protect the system from its influence, then, the substance of the organs themselves, the fat of the body, the substance of the muscles, the nerves, and the brain, are unavoidably consumed. The true cause of death in these cases is the respiratory process, that is, the action of the atmosphere.

A deficiency of food, and a want of power to convert the food into a part of the organism, are both, equally, a want of resistance; and this is the negative cause of the cessation of the vital process. The flame is extinguished, because the oil is consumed; and it is the oxygen of the air which has consumed it.

In many diseases substances are produced which are incapable of assimilation. By the mere deprivation of food, these substances are removed from the body without leaving a trace behind; their elements have entered into combination with the oxygen of the air.

From the first moment that the function of the lungs or of the skin is interrupted or disturbed, compounds, rich in carbon, appear in the urine, which acquires a brown color. Over the whole surface of the body oxygen is absorbed, and combines with all the substances which offer no resistance to it. In those parts of the body where the access of oxygen is impeded; for example, in the arm-pits, or in the soles of the feet, peculiar compounds are given out, recognisable by their appearance, or by their odor. These compounds contain much carbon.

Respiration is the falling weight—the bent spring, which keeps the clock in motion: the inspirations and expirations are the strokes of the pendulum which regulate it. In our ordinary time-pieces, we know with mathematical accuracy the effect produced on their rate of going, by changes in the length of the pendulum, or in the external temperature. Few, however, have a clear conception of the influence of air and temperature on the health of the human body; and yet the research into the conditions necessary to keep it in the normal state, is not more difficult than in the case of a clock.

LETTER VIII.

My Dear Sir:

Having attempted in my last letter to explain to you the simple and admirable office subserved by the oxygen of the atmosphere in its combination with carbon in the animal body, I will now proceed to present you with some remarks upon those materials which sustain its mechanisms in motion, and keep up their various functions—namely, the Aliments.

If the increase of mass in an animal body, the development and reproduction of its organs depend upon the blood, then those substances only which are capable of being converted into blood can be properly regarded as nourishment. In order then to ascertain what parts of our food are nutritious, we must compare the composition of the blood with the composition of the various articles taken as food.

Two substances require especial consideration as the chief ingredients of the blood; one of these separates immediately from the blood when it is withdrawn from the circulation.

It is well known that in this case blood coagulates, and separates into a yellowish liquid, the *serum* of the blood, and a gelatinous mass, which adheres to a rod or stick in soft, elastic fibres, when coagulating blood is briskly stirred. This is the *fibrine* of the blood, which is identical in all its properties with muscular fibre, when the latter is purified from all foreign matters.

The second principal ingredient of the blood is contained in the serum, and gives to this liquid all the properties of the white of eggs, with which it is indeed identical. When heated, it coagulates into a white elastic mass, and the coagulating substance is called *albumen*.

Fibrine and albumen, the chief ingredients of blood, contain, in all, seven chemical elements, among which nitrogen, phosphorus, and sulphur, are found. They contain also the earth of bones. The serum retains in solution sea salt and other salts of potash and soda, in which the acids are carbonic, phosphoric, and sulphuric acids. The globules of the blood contain fibrine and albumen, along with a red coloring matter, in which iron is a constant element. Beside these, the blood contains certain fatty bodies in small quantity, which differ from ordinary fats in several of their properties.

Chemical analysis has led to the remarkable result, that fibrine and albumen contain the same organic elements united in the same proportion—that is, that they are *isomeric*, their chemical composition—the proportion of their ultimate elements—being identical. But the difference of their external properties shows that the particles of which they are composed are arranged in a different order. (See *ante*, page 16.)

This conclusion has lately been beautifully confirmed by a distinguished physiologist (Dénis), who has succeeded in converting fibrine into albumen; that is, in giving it the solubility, and coagulability, by heat, which characterize the white of eggs.

Fibrine and albumen, beside having the same composition, agree also in this, that both dissolve in concentrated muriatic acid, yielding a solution of an intense purple color. This solution, whether made with fibrine or albumen, has the very same reactions with all substances yet tried.

Both albumen and fibrine, in the process of nutrition, are capable of being converted into muscular fibre, and muscular fibre is capable of being reconverted into blood. These facts have long been established by physiologists, and chemistry has merely proved that these metamorphoses can be accomplished under the influence of a certain force, without the aid of a third substance, or of its elements, and without the addition of any foreign element, or the separation of any element previously present in these substances.

If we now compare the composition of all organized parts with that of fibrine and albumen, the following relations present themselves:

All parts of the animal body which have a decided shape, which form parts of organs, contain nitrogen. No part of an organ which possesses motion and life is destitute of nitrogen; all of them contain likewise carbon and the elements of water; the latter, however, in no case in the proportion to form water.

The chief ingredients of the blood contain nearly seventeen per cent. of nitrogen, and from numerous analyses it appears that no part of an organ contains less than seventeen per cent. of nitrogen.

The most convincing experiments and observations have proved that the animal body is absolutely incapable of producing an elementary body, such as carbon or nitrogen, out of substances which do not contain it; and it obviously follows, that all kinds of food fit for the production either of blood, or of cellular tissue, membranes, skin, hair, muscular fibre, &c., must contain a certain amount of nitrogen, because that element is essential to the composition of the above-named organs; because the organs cannot create it from the other elements presented to them; and, finally, because no nitrogen is absorbed from the atmosphere in the vital process.

The substance of the brain and nerves contains a large quantity of albumen, and, in addition to this, two peculiar fatty acids, distinguished from other fats by containing phosphorus (phosphoric acid). One of these contains nitrogen (Frémy).

Finally, water and common fat are those ingredients of the body which are destitute of nitrogen. Both are amorphous, or unorganized, and only so far take part in the vital process as that their presence is required for the due performance of the vital functions. The inorganic constituents of the body are iron, lime, magnesia, common salt, and the alkalies.

The nutritive process is seen in its simplest form in carnivorous animals. This class of animals lives on the blood and flesh of the graminivora; but this blood and flesh are, in all their properties, identical with their own. Neither chemical nor physiological differences can be discovered.

The nutriment of carnivorous animals is derived originally from blood; in their stomach it becomes dissolved, and capable of reaching all other parts of the body; in its passage it is again converted into blood, and from this blood are reproduced all those parts of their organization which have undergone change or metamorphosis.

With the exception of hoofs, hair, feathers, and the earth of bones, every part of the food of carnivorous animals is capable of assimilation.

In a chemical sense, therefore, it may be said that a carnivorous animal, in supporting the vital process, consumes itself. That which serves for its nutrition is identical with those parts of its organization which are to be renewed.

The process of nutrition in graminivorous animals appears at first sight altogether different. Their digestive organs are less simple, and their food consists of vegetables, the great mass of which contains but little nitrogen.

From what substances, it may be asked, is the blood formed, by means of which their organs are developed? This question may be answered with certainty.

Chemical researches have shown, that all such parts of vegetables as can afford nutriment to animals contain certain constituents which are rich in nitrogen; and the most ordinary experience proves that animals require for their support and nutrition less of these parts of plants in proportion as they abound in the nitrogenized constituents. Animals cannot be fed on matters destitute of these nitrogenized constituents.

These important products of vegetation are especially abundant in the seeds of the different kinds of grain, and of peas, beans, and lentils; in the roots and the juices of what are commonly called vegetables. They exist, however, in all plants, without exception, and in every part of plants in larger or smaller quantity.

These nitrogenized forms of nutriment in the vegetable kingdom may be reduced to three substances, which are easily distinguished by their external characters. Two of them are soluble in water, the third is insoluble.

When the newly-expressed juices of vegetables are allowed to stand, a separation takes place in a few minutes. A gelatinous precipitate, commonly of a green tinge, is deposited, and this, when acted on by liquids which remove the coloring matter, leaves a grayish white substance, well known to druggists as the deposite from vegetable juices. This is one of the nitrogenized compounds which serves for the nutrition of animals, and has been named *vegetable fibrine*. The juice of grapes is especially rich in this constituent, but it is most abundant in the seeds of wheat, and of the cerealia generally. It may be obtained from wheat flour by a mechanical operation, and in a state of tolerable purity; it is then called *gluten*, but the glutinous property belongs, not to vegetable fibrine, but to a foreign substance, present in small quantity, which is not found in the other cerealia.

The method by which it is obtained sufficiently proves that it is insoluble in water; although we cannot doubt that it was originally dissolved in the vegetable juice, from which it afterwards separated, exactly as fibrine does from blood.

The second nitrogenized compound remains dissolved in the juice after the separation of the fibrine. It does not separate from the juice at the ordinary temperature, but is instantly coagulated when the liquid containing it is heated to the boiling point.

When the clarified juice of nutritious vegetables, such as cauliflower, asparagus, mangelwurzel, or turnips, is made to boil, a coagulum is formed, which it is absolutely impossible to distinguish from the substance which separates as a coagulum, when the serum of blood, or the white of an egg, diluted with water, are heated to the boiling point. This is *vegetable albumen.* It is found in the greatest abundance in certain seeds, in nuts, almonds, and others, in which the starch of the gramineæ is replaced by oil.

The third nitrogenized constituent of the vegetable food of animals is *vegetable caseine.* It is chiefly found in the seeds of peas, beans, lentils, and similar leguminous seeds. Like vegetable albumen, it is soluble in water, but differs from it in this, that its solution is not coagulated by heat. When the solution is heated or evaporated, a skin forms on its surface, and the addition of an acid causes a coagulum, just as in animal milk.

These three nitrogenized compounds, vegetable fibrine, albumen, and caseine, are the true nitrogenized constituents of the food of graminivorous animals; all other nitrogenized compounds occurring in plants, are either rejected by animals, as in the case of the characteristic principles of poisonous and medicinal plants, or else they occur in the food in such very small proportion, that they cannot possibly contribute to the increase of mass in the animal body.

The chemical analysis of these three substances has led to the very interesting result that they contain the same organic elements, united in the same proportion by weight; and, what is still more remarkable, that they are identical in composition with the chief constituents of blood, animal fibrine, and albumen. They all three dissolve in concentrated muriatic acid with the same deep purple color, and even in their physical characters, animal fibrine and albumen are in no respect different from vegetable fibrine and albumen. It is especially to be noticed, that by the phrase, identity of composition, we do not here intend mere similarity, but that even in regard to the presence and relative amount of sulphur, phosphorus, and phosphate of lime, no difference can be observed. How beautifully and admirably simple, with the aid of these discoveries, appears the process of nutrition in animals—the formation of their organs, in which vitality chiefly resides! Those vegetable principles, which in animals are used to form blood, contain the chief constituents of blood, fibrine and albumen, ready formed, as far as regards their composition. All plants, besides, contain a certain quantity of iron, which reappears in the coloring matter of the blood. Vegetable fibrine and animal fibrine, vegetable albumen and animal albumen, hardly differ, even in form; if these principles be wanting in the food, the nutrition of the animal is arrested; and when they are present, the graminivorous animal obtains in its food the very same principles on the presence of which the nutrition of the carnivora entirely depends.

Vegetables produce in their organism the blood of all animals, for the carnivora, in consuming the blood and flesh of the graminivora, consume, strictly speaking, only the vegetable principles which have served for the nutrition of the latter. Vegetable fibrine and albumen take the same form in the stomach of the graminivorous animal as animal fibrine and albumen do in that of the carnivorous animal.

From what has been said, it follows that the development of the animal organism and its growth are dependent on the reception of certain principles identical with the chief constituents of blood.

In this sense we may say that the animal organism gives to blood only its form; that it is incapable of creating blood out of other substances which do not already contain the chief constituents of that fluid. We cannot, indeed, maintain that the animal organism has no power to form other compounds, for we know that it is capable of producing an extensive series of compounds, differing in composition from the chief constituents of blood; but these last, which form the starting point of the series, it cannot produce.

The animal organism is a higher kind of vegetable, the development of which begins with those substances with the production of which the life of an ordinary vegetable ends. As soon as the latter has borne seed, it dies, or a period of its life comes to a termination.

In that endless series of compounds, which begins with carbonic acid, ammonia, and water, the sources of the nutrition of vegetables, and includes the most complex constituents of the animal brain, there is no blank, no interruption. The first substance capable of affording nutriment to animals is the last product of the creative energy of vegetables.

The substance of cellular tissue and of membranes, of the brain and nerves, these the vegetable cannot produce.

The seemingly miraculous in the productive agency of vegetables disappears in a great degree, when we reflect that the production of the constituents of blood cannot appear more surprising than the occurrence of the fat of beef and mutton in cocoa beans, of human fat in olive-oil, of the principal ingredient of butter in palm oil, and of horse fat and train-oil, in certain oily seeds.

LETTER IX.

MY DEAR SIR:

The facts detailed in my last letter will satisfy you as to the manner in which the increase of mass in an animal, that is its growth, is accomplished; we have still to consider a most important question, namely, the function performed in the animal system by substances destitute of nitrogen; such as sugar, starch, gum, pectine, &c.

The most extensive class of animals, the graminivora, cannot live without these substances; their food must contain a certain amount of one or more of them, and if these compounds are not supplied, death quickly ensues.

This important inquiry extends also to the constituents of the food of carnivorous animals in the earliest periods of life; for this food also contains substances which are not necessary for their support in the adult state. The nutrition of the young of carnivora is obviously accomplished by means similar to those by which the graminivora are nourished; their development is dependent on the supply of a fluid, which the body of the mother secretes in the shape of milk.

Milk contains only one nitrogenised constituent, known under the name of *caseine;* besides this, its chief ingredients are butter (fat), and sugar of milk. The blood of the young animal, its muscular fibre, cellular tissue, nervous matter, and bones, must have derived their origin from the nitrogenised constituent of milk—the caseine; for butter and sugar of milk contain no nitrogen.

Now, the analysis of caseine has led to the result, which, after the details I have given, can hardly excite your surprise, that this substance also is identical in composition with the chief constituents of blood, fibrine and albumen. Nay more—a comparison of its properties with those of vegetable caseine has shown—that these two substances are identical in all their properties; insomuch, that certain plants, such as peas, beans, and lentils, are capable of producing the same substance which is formed from the blood of the mother, and employed in yielding the blood of the young animal.

The young animal, therefore, receives in the form of caseine—which is distinguished from fibrine and albumen by its great solubility, and by not coagulating when heated—the chief constituent of the mother's blood. To convert caseine into blood no foreign substance is required, and in the conversion of the mother's blood into caseine, no elements of the constituents of the blood have been separated. When chemically examined, caseine is found to contain a much larger proportion of the earth of bones than blood does, and that in a very soluble form, capable of reaching every part of the body. Thus, even in the earliest period of its life, the development of the organs, in which vitality resides, is, in the carnivorous animal, dependent on the supply of a substance, identical in organic composition with the chief constituents of its blood.

What, then, is the use of the butter and the sugar of milk? How does it happen that these substances are indispensable to life?

Butter and sugar of milk contain no fixed bases, no soda or potash. Sugar of milk has a composition closely allied to that of the other kinds of sugar, of starch, and of gum; all of them contain carbon and the elements of water, the latter precisely in the proportion to form water.

There is added, therefore, by means of these compounds, to the nitrogenized constituents of food, a certain amount of carbon; or, as in the case of butter, of carbon and hydrogen; that is, an excess of elements, which cannot possibly be employed in the production of blood, because the nitrogenised substances contained in the food already contain exactly the amount of carbon which is required for the production of fibrine and albumen.

The following considerations will show that hardly a doubt can be entertained, that this excess of carbon alone, or of carbon and hydrogen, is expended in the production of animal heat, and serves to protect the organism from the action of the atmospheric oxygen, which is required for the production of fibrine and albumen.

In an adult carnivorous animal, which neither gains nor loses weight, perceptibly, from day to day, its nourishment, the waste of organized tissue, and its consumption of oxygen, stand to each other in a well-defined and fixed relation.

The carbon of the carbonic acid given off, with that of the urine; the nitrogen of the urine, and the hydrogen given off as ammonia and water; these elements, taken together, must be exactly equal in weight to the carbon, nitrogen, and hydrogen of the metamorphosed tissues, and since these last are exactly replaced by the food, to the carbon, nitrogen, and hydrogen of the food. Were this not the case, the weight of the animal could not possibly remain unchanged.

But, in the young of the carnivora, the weight does not remain unchanged; on the contrary, it increases from day to day by an appreciable quantity.

This fact presupposes, that the assimilative process in the young animal is more energetic, more intense, than the process of transformation in the existing tissues. If both processes were equally active, the weight of the body could not increase; and were the waste by transformation greater, the weight of the body would decrease.

Now, the circulation in the young animal is not weaker, but, on the contrary, more rapid; the respirations are more frequent; and, for equal bulks, the consumption of oxygen must be greater rather than smaller in the young than in the adult animal. But, since the metamorphosis of organized parts goes on more slowly, there would ensue a deficiency of those substances, the carbon and hydrogen of which are adapted for combination with oxygen; because, in the carnivora, it is the new compounds, produced by the metamorphosis of organized parts, which nature has destined to furnish the necessary resistance to the action of the oxygen, and to produce animal heat. What is wanting for these purposes Infinite Wisdom has supplied to the young animal in its natural food.

The carbon and hydrogen of butter, and the carbon of the sugar of milk, no part of either of which can yield blood, fibrine, or albumen, are destined for the support of the respiratory process, at an age when a greater resistance is opposed to the metamorphosis of existing organisms; or, in other words, to the production of compounds, which, in the adult state, are produced in quantity amply sufficient for the purpose of respiration.

The young animal receives the constituents of its blood in the caseine of the milk. A metamorphosis of existing organs goes on, for bile and urine are secreted; the matter of the metamorphosed parts is given off in the form of urine, of carbonic acid, and of water; but the butter and sugar of milk also disappear; they cannot be detected in the fæces.

The butter and sugar of milk are given out in the form of carbonic acid and water, and their conversion into oxidized products furnishes the clearest proof that far more oxygen is absorbed than is required to convert the carbon and hydrogen of the metamorphosed tissues into carbonic acid and water.

The change and metamorphosis of organized tissues going on in the vital process in the young animal, consequently yield, in a given time, much less carbon and hydrogen in the form adapted for the respiratory process than corresponds to the oxygen taken up in the lungs. The substance of its organized parts would undergo a more rapid consumption, and would necessarily yield to the action of the oxygen, were not the deficiency of carbon and hydrogen supplied from another source.

The continued increase of mass, or growth, and the free and unimpeded development of the organs in the young animal, are dependent on the presence of foreign substances, which, in the nutritive process, have no other function than to protect the newly-formed organs from the action of the oxygen. It is the elements of these substances which unite with the oxygen; the organs themselves could not do so without being consumed; that is, growth, or increase of mass in the body—the consumption of oxygen remaining the same—would be utterly impossible.

The preceding considerations leave no doubt as to the purpose for which Nature has added to the food of the young of carnivorous mammalia substances devoid of nitrogen, which their organism cannot employ for nutrition, strictly so called, that is, for the production of blood; substances which may be entirely dispensed with in their nourishment in the adult state. In the young of carnivorous birds, the want of all motion is an obvious cause of diminished waste in the organized parts; hence, milk is not provided for them.

The nutritive process in the carnivora thus presents itself under two distinct forms; one of which we again meet with in the graminivora.

In graminivorous animals, we observe, that during their whole life, their existence depends on a supply of substances having a composition identical with that of sugar of milk, or closely resembling it. Every thing that they consume as food contains a certain quantity of starch, gum, or sugar, mixed with other matters.

The function performed in the vital process of the graminivora by these substances is indicated in a very clear and convincing manner, when we take into consideration the very small relative amount of the carbon which these animals consume in the nitrogenized constituents of their food, which bears no proportion whatever to the oxygen absorbed through the skin and lungs.

A horse, for example, can be kept in perfectly good condition, if he obtain as food fifteen pounds of hay and four and a half pounds of oats, daily. If we now calculate the whole amount of nitrogen in these matters, as ascertained by analysis (1.5 per cent. in the hay, 2.2 per cent. in the oats), in the form of blood, that is, as fibrine and albumen, with the due proportion of water in blood (eighty per cent.), the horse receives daily no more than four and a half ounces of nitrogen, corresponding to about eight pounds of blood. But along with this nitrogen, that is, combined with it in the form of fibrine or albumen, the animal receives only about fourteen and a half ounces of carbon.

Without going further into the calculation, it will readily be admitted, that the volume of air inspired and expired by a horse, the quantity of oxygen consumed, and, as a necessary consequence, the amount of carbonic acid given out by the animal, is much greater than in the respiratory process in man. But an adult man consumes daily about fourteen ounces of carbon, and the determination of Boussingault, according to which a horse expires seventy-nine ounces daily, cannot be very far from the truth.

In the nitrogenized constituents of his food, therefore, the horse receives rather less than the fifth part of the carbon which his organism requires for the support of the respiratory process; and we see that the wisdom of the Creator has added to his food the four-fifths which are wanting, in various forms, as starch, sugar, &c., with which the animal must be supplied, or his organism will be destroyed by the action of the oxygen.

It is obvious, that, in the system of the graminivora, whose food contains so small a portion, relatively, of the constituents of blood, the process of metamorphosis in existing tissues, and consequently their restoration or reproduction, must go on far less rapidly than in the carnivora. Were this not the case, a vegetation a thousand times more luxuriant than the actual one would not suffice for their nourishment. Sugar, gum, and starch, would no longer be necessary to support life in these animals, because, in that case, the products of the waste, or metamorphosis of the organized tissues, would contain enough of carbon to support the respiratory process.

LETTER X.

My Dear Sir:

Let me now apply the principles announced in the preceding letters to the circumstances of our own species. Man, when confined to animal food, requires for his support and nourishment extensive sources of food, even more widely extended than the lion and tiger, because, when he has the opportunity, he kills without eating.

A nation of hunters, on a limited space, is utterly incapable of increasing its numbers beyond a certain point, which is soon attained. The carbon necessary for respiration must be obtained from the animals, of which only a limited number can live on the space supposed. These animals collect from plants the constituents of their organs and of their blood, and yield them, in turn, to the savages who live by the chase alone. They, again, receive this food unaccompanied by those compounds, destitute of nitrogen, which, during the life of the animals, served to support the respiratory process. In such men, confined to an animal diet, it is the carbon of the flesh and of the blood which must take the place of starch and sugar.

But fifteen pounds of flesh contain no more carbon than four pounds of starch, and while the savage, with one animal and an equal weight of starch, could maintain life and health for a certain number of days, he would be compelled, if confined to flesh alone, in order to procure the carbon necessary for respiration, during the same time, to consume five such animals.

It is easy to see, from these considerations, how close the connexion is between agriculture and the multiplication of the human species. The cultivation of our crops has ultimately no other object than the production of a maximum of those substances which are adapted for assimilation and respiration, in the smallest possible space. Grain and other nutritious vegetables yield us, not only in starch, sugar, and gum, the carbon which protects our organs from the action of oxygen, and produces in the organism the heat which is essential to life, but also in the form of vegetable fibrine, albumen, and caseine, our blood, from which the other parts of our body are developed.

Man, when confined to animal food, respires, like the carnivora, at the expense of the matters produced by the metamorphosis of organized tissues; and, just as the lion, tiger, hyæna in the cages of a menagerie, are compelled to accelerate the waste of the organized tissue by incessant motion, in order to furnish the matter necessary for respiration, so the savage, for the very same object, is forced to make the most laborious exertions, and go through a vast amount of muscular exercise. He is compelled to consume force merely in order to supply matter for respiration.

Cultivation is the economy of force. Science teaches us the simplest means of obtaining the *greatest* effect with the *smallest* expenditure of power, and with given means to produce a maximum of force. The unprofitable exertion of power, the waste of force in agriculture, in other branches of industry, in science, or in social economy, is characteristic of the savage state, or of the want of knowledge.

In accordance with what I have already stated, you will perceive that the substances, of which the food of man is composed, may be divided into two classes; into *nitrogenized* and *non-nitrogenized*. The former are capable of conversion into blood; the latter are incapable of this transformation.

Out of those substances, which are adapted to the formation of blood, are formed all the organized tissues. The other class of substances, in the normal state of health, serve to support the process of respiration. The former may be called the *plastic elements of nutrition;* the latter, *elements of respiration.*

Among the former we reckon—

Vegetable fibrine.
Vegetable casine.
Animal blood.
Vegetable Albumen.
Animal flesh.

Among the elements of respiration in our food are—

Fat.
Starch.
Gum.
Cane Sugar.
Grape Sugar.
Sugar of milk.
Pectine.
Bassorine.
Wine.
Beer.
Spirits.

The most recent and exact researches have established as a universal fact, to which nothing yet known is opposed, that the nitrogenized constituents of vegetable food have a composition identical with that of the constituents of the blood.

No nitrogenized compound, the composition of which differs from that of fibrine, albumen, and caseine, is capable of supporting the vital process in animals.

The animal organism unquestionably possesses the power of forming, from the constituents of its blood, the substance of its membranes and celular tissue, of the nerves and brain, and of the organic part of cartilages and bones. But the blood must be supplied to it ready formed in every thing but its form—that is, in its chemical composition. If this be not done, a period is rapidly put to the formation of blood, and consequently to life.

This consideration enables us easily to explain how it happens that the tissues yielding gelatine or chondrine, as, for example, the gelatine of skin or of bones, are not adapted for the support of the vital process; for their composition is different from that of fibrine or albumen. It is obvious that this means nothing more than that those parts of the animal organism, which form the blood, do not possess the power of effecting a transformation in the arrangement of the elements of gelatine, or of those tissues which contain it. The gelatinous tissues, the gelatine of the bones, the membranes, the cells, and the skin, suffer in the animal body, under the influence of oxygen and moisture, a progressive alteration; a part of these tissues is separated, and must be restored from the blood; but this alteration and restoration is obviously confined within very narrow limits.

While, in the body of a starving or sick individual, the fat disappears, and the muscular tissue takes once more the form of blood, we find that the tendons and membranes retain their natural condition; the limbs of the dead body retain their connexions, which depend on the gelatinous tissues.

On the other hand, we see that the gelatine of bones devoured by a dog entirely disappears, while only the bone earth is found in his excrements. The same is true of a man, when fed on food rich in gelatine, as for example, strong soup. The gelatine is not to be found either in the urine or in the fæces, and consequently must have undergone a change, and must have served some purpose in the animal economy. It is clear that the gelatine must be expelled from the body in a form different from that in which it was introduced as food.

When we consider the transformation of the albumen of the blood into a part of an organ composed of fibrine, the identity in composition of the two substances renders the change easily conceivable. Indeed, we find the change of a dissolved substance into an insoluble organ of vitality, chemically speaking, natural and easily explained, on account of this very identity of composition. Hence, the opinion is not unworthy of a closer investigation, that gelatine, when taken in the dissolved state, is again converted, in the body, into celular tissue, membrane, and cartilage; that it may serve for the re-production of such parts of these tissues as have been wasted, and for their growth.

And when the powers of nutrition in the whole body are effected by a change of the health, then, even should the power of forming blood remain the same, the organic force by which the constituents of the blood are transformed into cellular tissue and membranes must necessarily be enfeebled by sickness. In the sick man, the intensity of the vital force, its power to produce metamorphoses, must be diminished as well in the stomach as in all other parts of the body. In this condition, the uniform experience of practical physicians shows that gelatinous matters, in a dissolved state, exercise a most decided influence on the state of the health. Given in a form adapted for assimilation, they serve to husband the vital force, just as may be done in the case of the stomach, by due preparation of the food in general.

Brittleness in the bones of graminivorous animals is clearly owing to a weakness in those parts of the organism whose function it is to convert the constituents of the blood into cellular tissue and membrane; and if we can trust to the reports of physicians who have resided in the East, the Turkish women, in their diet of rice, and in the frequent use of enemata of strong soup, have united the conditions necessary for the formation both of cellular tissue and of fat.

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LETTER XI.

My Dear Sir:

In the immense, yet limited expanse of the ocean, the animal and vegetable kingdoms are mutually dependent upon, and successive to, each other. The animals obtain their constituent elements from the plants, and restore them to the water in their original form, when they again serve as nourishment to a new generation of plants.

The oxygen, which marine animals withdraw in their respiration from the air, dissolved in sea-water, is returned to the water by the vital processes of sea plants; that air is richer in oxygen than atmospheric air, containing thirty-two to thirty-three per cent., while the latter contains only twenty-one per cent. Oxygen also combines with the products of the putrefaction of dead animal bodies, changes their carbon into carbonic acid, their hydrogen into water, and their nitrogen assumes again the form of ammonia.

Thus we observe in the ocean a circulation takes place without the addition or abstraction of any element, unlimited in duration, although limited in extent, inasmuch as in a confined space the nourishment of plants exists in a limited quantity.

We well know that marine plants cannot derive a supply of *humus* for their nourishment through their roots. Look at the great sea-tang, the *Fucus Gigantius:* this plant, according to Cook, reaches a height of three hundred and sixty feet, and a single specimen, with its immense ramifications, nourishes thousands of marine animals; yet its root is a small body, no larger than the fist. What nourishment can this draw from a naked rock, upon the surface of which there is no perceptible change? It is quite obvious that these plants require only a hold—a fastening to prevent a change of place—as a counterpoise to their specific gravity, which is less than that of the medium in which they float. That medium provides the necessary nourishment, and presents it to the surface of every part of the plant. Sea-water contains not only carbonic acid and ammonia, but the alkaline and earthy phosphates and carbonates required by these plants for their growth, and which we always find as constant constituents of their ashes.

All experience demonstrates that the conditions of the existence of marine plants are the same which are essential to terrestrial plants. But the latter do not live like sea plants, in a medium which contains all their elements, and surrounds with appropriate nourishment every part of their organs; on the contrary, they require two media, of which one, namely the soil, contains those essential elements which are absent from the medium surrounding them, that is, the atmosphere.

Is it possible that we could ever be in doubt respecting the office which the soil and its component parts subserve in the existence and growth of vegetables?—that there should have been a time when the mineral elements of plants were not regarded as absolutely essential to their vitality? Has not the same circulation been observed on the surface of the earth, which we have just contemplated in the ocean—the same incessant change, disturbance, and restitution of equilibrium?

Experience in agriculture shows that the production of vegetables on a given surface increases with the supply of certain matters, originally parts of the soil which had been taken up from it by plants—the excrements of man and animals. These are nothing more than matters derived from vegetable food, which in the vital processes of animals, or after their death, assume again the form under which they originally existed, as parts of the soil. Now, we know that the atmosphere contains none of these substances, and, therefore, can replace none; and we know that their removal from a soil destroys its fertility, which may be restored and increased by a new supply.

Is it possible, after so many decisive investigations into the origin of the elements of animals and vegetables, the use of the alkalies, of lime and the phosphates, any doubt can exist as to the principles upon which a rational agriculture depends? Can the art of agriculture be based upon any thing but the restitution of a disturbed equilibrium? Can it be imagined, that any country, however rich and fertile, with a flourishing commerce, which for centuries exports its produce in the shape of grain and cattle, will maintain its fertility, if the same commerce does not restore, in some form of manure, those elements which have been removed from the soil, and which cannot be replaced by the atmosphere? Must not the same fate await every such country which has actually befallen the once prolific soil of Virginia, now in many parts no longer able to grow its former staple productions—wheat and tobacco?

In the large towns of England the produce both of English and foreign agriculture is largely consumed; elements of the soil, indispensable to plants, do not return to the fields—contrivances resulting from the manners and customs of English people, and peculiar to them, render it difficult, perhaps impossible, to collect the enormous quantity of the phosphates, which are daily, as solid and liquid excrements, carried into the rivers. These phoshates, although present in the soil in the smallest quantity, are its most important mineral constituents. It was observed that many English fields exhausted in that manner, immediately doubled their produce, as if by a miracle, when dressed with bone-earth imported from the continent. But if the export of bones from Germany is continued to the extent it has hitherto reached, our soil must be gradually exhausted, and the extent of our loss may be estimated, by considering that one pound of bones contains as much phosphoric acid as a hundred weight of grain.

The imperfect knowledge of nature, and the properties and relations of matter, possessed by the alchemists, gave rise, in their time, to an opinion that metals as well as plants could be produced from a *seed*. The regular forms and ramifications seen in crystals, they imagined to be the leaves and branches of metal plants; and as they saw the seed of plants grow, producing root, stem, and leaves, and again blossoms, fruits, and seeds, apparently without receiving any supply of appropriate material, they deemed it worthy of zealous inquiry to discover the *seed* of gold, and the earth necessary for its development. If the metal seeds were once obtained, might they not entertain hope of their growth? Such ideas could only be entertained when nothing was known of the atmosphere, and its participation with the earth, in administering to the vital processes of plants and animals. Modern chemistry, indeed, produces the elements of water, and combining them, forms water anew; but it does not *create* those elements—it derives them from water; the new-formed artificial water has been water before.

Many of our farmers are like the alchemists of old—they are searching for the miraculous seed—the means, which, without any further supply of nourishment to a soil scarcely rich enough to be sprinkled with indigenous plants, shall produce crops of grain a hundred fold.

The experience of centuries, nay, of thousands of years, is insufficient to guard men against these fallacies; our only security from these and similar absurdities must be derived from a correct knowledge of scientific principles.

In the first period of natural philosophy organic life was supposed to be derived from water only; afterward, it was admitted that certain elements derived from the air must be superadded to the water; but we *now* know that other elements must be supplied by the earth, if plants are to thrive and multiply.

The amount of materials contained in the atmosphere, suited to the nourishment of plants, is limited; but it must be abundantly sufficient to cover the whole surface of the earth with a rich vegetation. Under the tropics, and in those parts of our globe where the most genial conditions of fertility exist—a suitable soil, a moist atmosphere, and a high temperature—vegetation is scarcely limited by space; and, where the soil is wanting, it is gradually supplied by the decaying leaves, bark, and branches of plants. It is obvious there is no deficiency of atmospheric nourishment for plants in those regions, nor are these wanting in our own cultivated fields: all which plants require for their development is conveyed to them by the incessant motions of the atmoshere. The air between the tropics contains no more than that of the arctic zones; and yet how different is the amount of produce of an equal surface of land in the two situations!

This is easily explicable. All the plants of tropical climates, the oil and wax palms, the sugar cane, &c., contain only a small quantity of the elements of the blood necessary to the nutrition of animals, as compared with our cultivated plants. The tubers of the potato in Chili, its native country, where the plant resembles a shrub, if collected from an acre of land, would scarcely suffice to maintain an Irish family for a single day (Darwin.) The result of cultivation in those plants which serve as food is to produce in them those constituents of the blood. In the absence of the elements essential to these in the soil, starch, sugar, and woody fibre, are, perhaps, formed; but no vegetable fibrine, albumen, or caseine. If we intend to produce on a given surface of soil more of these latter matters than the plants can obtain from the atmosphere, or receive from the soil of the same surface in its uncultivated and normal state, we must *create* an artificial atmosphere, and add the needed elements to the soil.

The nourishment which must be supplied in a given time to different plants, in order to admit a free and unimpeded growth, is very unequal.

On pure sand, on calcareous soil, on naked rocks, only a few genera of plants prosper, and these are, for the most part, perennial plants. They require, for their slow growth, only such minute quantities of mineral substances as the soil can furnish, which may be totally barren for other species. Annual, and especially summer plants, grow and attain their perfection in a comparative short time; they therefore do not prosper on a soil which is poor in those mineral substances necessary to their development. To attain a maximum in height in the short period of their existence the nourishment contained in the atmosphere is not sufficient. If the end of cultivation is to be obtained we must create in the soil an artificial atmosphere of carbonic acid and ammonia; and this surplus of nourishment, which the leaves cannot appropriate from the air, must be taken up by the corresponding organs, that is, the roots, from the soil. But the ammonia, together with the carbonic acid, are alone insufficient to become part of a plant destined to the nourishment of animals. In the absence of the alkalies, the phosphates and other earthy salts, no vegetable fibrine, no vegetable caseine, can be formed. The phosphoric acid of the phosphate of lime, indispensable to the ceralia and other vegetables in the formation of their seeds, is separated as an excrement, in great quantities, by the rind and bark of ligneous plants.

How different are the evergreen plants, the oleaginous plants, the mosses, the ferns, and the pines, from our annual grasses, the ceralia and leguminous vegetables! The former, at every time of the day during winter and summer, obtain carbon through their leaves by absorbing carbonic acid which is not furnished by the barren soil on which they grow; water is also absorbed and retained by their coriaceous or fleshy leaves with great force. They lose very little by evaporation, compared with other plants. On the other hand, how very small is the quantity of mineral substances which they withdraw from the soil during their almost constant growth in one year, in comparison with the quantity which one crop of wheat of an equal weight receives in three months!

It is by means of moisture that plants receive the necessary alkalies and salts from the soil. In dry summers a phenomenon is observed, which, when the importance of mineral elements to the life of a plant was unknown, could not be explained. The leaves of plants first developed and perfected, and, therefore, nearer the surface of the soil, shrivel up and become yellow, lose their vitality, and fall off while the plant is in an active state of growth, without any visible cause. This phenomenon is not seen in moist years, nor in evergreen plants, and but rarely in plants which have long and deep roots, nor is it seen in perennials in autumn and winter.

The cause of this premature decay is now obvious. The perfectly developed leaves absorb continually carbonic acid and ammonia from the atmosphere, which are converted into elements of new leaves, buds, and shoots; but this metamorphosis cannot be effected without the aid of the alkalies, and other mineral substances. If the soil is moist, the latter are continually supplied to an adequate amount, and the plant retains its lively green color; but if this supply ceases from a want of moisture to dissolve the mineral elements, a separation takes place in the plant itself. The mineral constituents of the juice are withdrawn from the leaves already formed, and are used for the formation of the young shoots; and as soon as the seeds are developed, the vitality of the leaves completely ceases. These withered leaves contain only minute traces of soluble salts, while the buds and shoots are very rich in them.

On the other hand, it has been observed, that where a soil is too highly impregnated with soluble saline materials, these are separated upon the surface of the leaves. This happens to culinary vegetables especially, whose leaves become covered with a white crust. In consequence of these exudations the plant sickens, its organic activity decreases, its growth is disturbed; and if this state continues long, the plant dies. This is most frequently seen in foliaceous plants, the large surfaces of which evaporate considerable quantities of water. Carrots, pumpkins, peas, &c., are frequently thus diseased, when, after dry weather, the plant being near its full growth, the soil is moistened by short showers, followed again by dry weather. The rapid evaporation carries off the water absorbed by the root, and this leaves the salts in the plant in a far greater quantity than it can assimilate. These salts effloresce upon the surface of the leaves, and if they are herbaceous and juicy, produce an effect upon them as if they had been watered with a solution containing a greater quantity of salts than their organism can bear.

Of two plants of the same species, this disease befalls that which is nearest its perfection; if one should have been planted later, or be more backward in its development, the same external cause which destroys the one will contribute to the growth of the other.

LETTER XII.

My dear Sir:

Having now occupied several letters with the attempt to unravel, by means of chemistry, some of the most curious functions of the animal body, and, as I hope, made clear to you the distinctions between the two kinds of constituent elements in food, and the purposes they severally subserve in sustaining life, let me now direct your attention to a scarcely less interesting and equally important subject—the means of obtaining from a given surface of the earth the largest amount of produce adapted to the food of man and animals.

Agriculture is both a science and an art. The knowledge of all the conditions of the life of vegetables, the origin of their elements, and the sources of their nourishment, form its scientific basis.

From this knowledge we derive certain rules for the exercise of the art, the principles upon which the mechanical operations of farming depend, the usefulness or necessity of these for preparing the soil to support the growth of plants, and for removing every obnoxious influence. No experience, drawn from the exercise of the art, can be opposed to true scientific principles, because the latter should include all the results of practical operations, and are in some instances solely derived therefrom. Theory must correspond with experience, because it is nothing more than the reduction of a series of phenomena to their last causes.

A field, in which we cultivate the same plant for several successive years, becomes barren for that plant in a period varying with the nature of the soil: in one field it will be in three, in another in seven, in a third in twenty, in a fourth in a hundred years. One field bears wheat, and no peas; another beans and turnips, but no tobacco; a third gives a plentiful crop of turnips, but will not bear clover. What is the reason that a field loses its fertility for one plant, the same which at first flourished there? What is the reason one kind of plant succeeds in a field where another fails?

These questions belong to science.

What means are necessary to preserve to a field its fertility for one and the same plant?—what to render one field fertile for two, for three, for all plants?

These last questions are put by Art, but they cannot be answered by Art.

If a farmer, without the guidance of just scientific principles, is trying experiments to render a field fertile for a plant which it otherwise will not bear, his prospect of success is very small. Thousands of farmers try such experiments in various directions, the result of which is a mass of practical experience forming a method of cultivation which accomplishes the desired end for certain places; but the same method frequently does not succeed—it indeed ceases to be applicable to a second or third place in the immediate neighborhood. How large a capital, and how much power, are wasted in these experiments! Very different, and far more secure, is the path indicated by science; it exposes us to no danger of failing, but on the contrary, it furnishes us with every guarantee of success. If the cause of failure—of barrenness in the soil for one or two plants—has been discovered, means to remedy it may readily be found.

The most exact observations prove that the method of cultivation must vary with the geognostical condition of the subsoil. In basalt, graywacke, porphyry, sandstone, limestone, &c., are certain elements indispensable to the growth of plants, and the presence of which renders them fertile. This fully explains the difference in the necessary methods of culture for different places; since it is obvious that the essential elements of the soil must vary with the varieties of composition of the rocks, from the disintegration of which they originated,

Wheat, clover, turnips, for example, each require certain elements from the soil; they will not flourish where the appropriate elements are absent. Science teaches us what elements are essential to every species of plants by an analysis of their ashes. If, therefore, a soil is found wanting in any of those elements, we discover at once the cause of its barrenness, and its removal may now be readily accomplished.

The empiric attributes all his success to the mechanical operations of agriculture; he experiences and recognises their value, without inquiring what are the causes of their utility, their mode of action: and yet this scientific knowledge is of the highest importance for regulating the application of power and the expenditure of capital—for insuring its economical expenditure and the prevention of waste. Can it be imagined that the mere passing of the ploughshare, or the harrow, through the soil—the mere contact of the iron—can impart fertility miraculously? Nobody, perhaps, seriously entertains such an opinion. Nevertheless, the *modus operandi* of these mechanical operations is by no means generally understood. The fact is quite certain, that careful ploughing exerts the most favorable influence: the surface is thus mechanically divided, changed, increased, and renovated: but the ploughing is only auxiliary to the end sought.

In the effects of time, in what in Agriculture are technically called *fallows*—the repose of the fields—we recognise by science certain chemical actions, which are continually exercised by the elements of the atmosphere upon the whole surface of our globe. By the action of its oxygen and its corbonic acid, aided by water, rain, changes of temperature, &c., certain elementary constituents of rocks, or of their ruins, which form the soil capable of cultivation, are rendered soluble in water, and consequently become separable from all their insoluble parts.

These chemical actions, poetically denominated the "tooth of time," destroy all the works of man, and gradually reduce the hardest rocks to the condition of dust. By their influence the necessary elements of the soil become fitted for assimilation by plants; and it is precisely the end which is obtained by the mechanical operations of farming. They accelerate the decomposition of the soil, in order to provide a new generation of plants with the necessary elements in a condition favorable to their assimilation. It is obvious that the rapidity of the decomposition of a solid body must increase with the extension of its surface; the more points of contact we offer in a given time to the external chemical agent, the more rapid will be its action.

The chemist, in order to prepare a mineral for analyis, to decompose it, or to increase the solubility of its elements, proceeds in the same way as the farmer deals with his fields—he spares no labor in order to reduce it to the finest powder; he separates the impalpable from the coarser parts by washing, and repeats his mechanical bruising and trituration, being assured his whole process will fail if he is inattentive to this essential and preliminary part of it.

The influence which the increase of surface exercises upon the disintegration of rocks, and upon the chemical action of air and moisture, is strikingly illustrated upon a large scale in the operations pursued in the gold mines of Yaquil, in Chili. These are described in a very interesting manner by Darwin. The rock containing the gold ore is pounded by mills into the finest powder; this is subjected to washing, which separates the lighter particles from the metallic; the gold sinks to the bottom, while a stream of water carries away the lighter earthy parts into ponds, where it subsides to the bottom as mud. When this deposit has gradually filled up the pond, this mud is taken out and piled in heaps, and left exposed to the action of the atmosphere and moisture. The washing completely removes all the soluble part of the disintegrated rock; the insoluble part, moreover, cannot undergo any further change while it is covered with water, and so excluded from the influence of the atmoshere at the bottom of the pond. But, being exposed at once to the air and moisture, a powerful chemical action takes place in the whole mass, which becomes indicated by an efflorescence of salts covering the whole surface of the heaps in considerable quantity. After being exposed for two or three years, the mud is again subjected to the same process of washing, and a considerable quantity of gold is obtained, this having been separated by the chemical process of decomposition in the mass. The exposure and washing of the same mud is repeated six or seven times, and at every washing it furnishes a new quantity of gold, although its amount diminishes every time.

Precisely similar is the chemical action which takes place in the soil of our fields; and we accelerate and increase it by the mechanical operations of agriculture. By these we sever and extend the surface, and endeavor to make every atom of the soil accessible to the action of the carbonic acid and oxygen of the atmosphere. We thus produce a stock of soluble mineral substances, which serve as nourishment to a new generation of plants, and which are indispensable to their growth and prosperity.

LETTER XIII.

My Dear Sir:

Having in my last letter spoken of the general principles upon which the science and art of agriculture must be based, let me now direct your attention to some of those particulars, which will more forcibly exhibit the connexion between chemistry and agriculture, and demonstrate the impossibility of perfecting the important art of rearing food for man and animals without a profound knowledge of our science.

All plants, cultivated as food, require for their healthy sustenance the alkalies and alkaline earths, each in a certain proportion; and in addition to these, the ceralia do not succeed in a soil destitute of *silica* in a soluble condition. The combinations of this substance, found as natural productions, namely, the silicates, differ greatly in the degree of facility with which they undergo decomposition, in consequence of the unequal resistance opposed by their integral parts to the dissolving power of the atmospheric agencies. Thus, the granite of Corsica degenerates into a powder in a time which scarcely suffices to deprive the polished granite of Heidelberg of its lustre.

Some soils abound in silicates so readily decomposable, that in every one or two years, as much silicate of potash becomes soluble and fitted for assimilation as is required by the leaves and straw of a crop of wheat. In Hungary, extensive districts are not uncommon where wheat and tobacco have been grown alternately upon the same soil for centuries, the land never receiving back any of those mineral elements which were withdrawn in the grain and straw. On the other hand, there are fields in which the necessary amount of soluble silicate of potash for a single crop of wheat is not separated from the insoluble masses in the soil in less than two, three, or even more years.

The term *fallow*, in Agriculture, designates that period in which the soil, left to the influence of the atmosphere, becomes enriched with those soluble mineral constituents. *Fallow*, however, does not generally imply an entire cessation of cultivation, but only an interval in the growth of the ceralia. That store of silicates and alkalies which is the principal condition of their success is obtained, if potatoes or turnips are grown upon the same fields in the intermediate periods, since these crops do not abstract a particle of silica, and therefore leave the field equally fertile for the following crop of wheat.

The preceding remarks will render it obvious to you, that the mechanical working of the soil is the simplest and cheapest method of rendering the elements of nutrition contained in it accessible to plants.

But it may be asked, Are there not other means of decomposing the soil besides its mechanical subdivision?—are there not substances, which, by their chemical operation, shall equally well or better render its constituents suitable for entering into vegetable organisms? Yes: we certainly possess such substances, and one of them, namely, quick-lime, has been employed for the last century past in England for this purpose; and it would be difficult to find a substance better adapted to this service, as it is simple, and in almost all localities cheap and easily accessible.

In order to obtain correct views respecting the effect of quick-lime upon the soil, let me remind you of the first process employed by the chemist when he is desirous of analysing a mineral, and for this purpose wishes to bring its elements into a soluble state. Let the mineral to be examined be, for instance, feldspar; this substance, taken alone, even when reduced to the finest powder, requires for its solution to be treated with an acid for weeks or months; but if we first mix it with quick-lime, and expose the mixture to a moderately strong heat, the lime enters into chemical combination with certain elements of the feldspar, and its alkali (potass) is set free. And now, the acid, even without heat, dissolves not only the lime, but also so much of the *silica* of the feldspar as to form a transparent jelly. The same effect which the lime in this process, with the acid of heat, exerts upon the feldspar, it produces when it is mixed with the alkaline argillaceous silicates, and they are for a long time kept together in a moist state.

Common potters' clay, or pipe-clay, diffused through water, and added to milk of lime, thickens immediately upon mixing; and if the mixture is kept for some months, and then treated with acid, the clay becomes gelatinous, which it would not have done without the admixture with the lime. The lime, in combining with the elements of the clay liquifies it; and, what is more remarkable, liberates the greater part of its alkalies. These interesting facts were first observed by Fuchs, at Munich: they have not only led to a more intimate knowledge of the nature and properties of the hydraulic cements, but, what is far more important, they explain the effects of caustic lime upon the soil, and guide the agriculturist in the application of an invaluable means of opening it, and setting free its alkalies—substances so important, nay, so indispensable to his crop.

In the month of October the fields of Yorkshire and Oxfordshire look as if they were covered with snow. Whole square miles are seen whitened over with quick-lime, which, during the moist winter months, exercises its beneficial influence upon the stiff, clayey soil, of those counties.

According to the humus theory, quicklime ought to exert the most noxious influence upon the soil, because all organic matters contained in it are destroyed by it, and rendered incapable of yielding their humus to a new vegetation. The facts are indeed directly contrary to this now abandoned theory: the fertility of the soil is increased by the lime.

The ceralia require the alkalies and alkaline silicates, which the action of the lime renders fit for assimilation by the plants. If, in addition to these, there is any decaying organic matter present in the soil supplying carbonic acid, it may facilitate their development; but it is not essential to their growth. If we furnish the soil with ammonia, and the phosphates, which are indispensable to the ceralia, with the alkaline silicates, we have all the conditions necessary to ensure an abundant harvest. The atmosphere is an inexhaustible store of carbonic acid.

A no less favorable influence than that of lime is exercised upon the soil of peaty land by the mere act of burning it: this greatly enhances its fertility. We have not long been acquainted with the remarkable change which the properties of clay undergo by burning. The observation was first made in the process of analysing the clay silicates. Many of these, in their natural state, are not acted on by acids, but they become perfectly soluble if heated to redness before the application of the acid. This property belongs to potters' clay, pipe-clay, loam, and many different modifications of clay in soils. In their natural state they may be boiled in concentrated sulphuric acid, without sensible change; but if freely burned, as is done with the pipe-clay in many alum manufactories, they dissolve in the acid with the greatest facility, the contained silica being separated like a jelly in a soluble state. Potters' clay belongs to the most sterile kinds of soil, and yet it contains within itself all the constituent elements essential to a most luxurious growth of plants; but their mere presence is insufficient to secure this end. The soil must be accessible to the atmosphere, to its oxygen, to its carbonic acid;—these must penetrate it, in order to secure the conditions necessary to a happy and vigorous development of the roots. The elements present must be brought into that peculiar state of combination which will enable them to enter into plants. Plastic clay is wanting in these properties; but they are imparted to it by a feeble calcination.

At Hardwicke Court, near Gloucester, I have seen a garden (Mr. Baker's) consisting of a stiff clay, which was perfectly sterile, become, by mere burning, extremely fertile. The operation was extended to a depth of three feet. This was an expensive process, certainly; but it was effectual.

The great difference in the properties of burnt and unburnt clay is illustrated by what is seen in brick houses, built in moist situations. In the towns of Flanders, for instance, where most buildings are of brick, efflorescences of salts cover the surfaces of the walls, like a white nap, within a few days after they are erected. If this saline incrustation is washed away by the rain, it soon reappears; and this is even observed on walls which, like the gateway of Lisle, have been erected for centuries. These saline incrustations consist of carbonates and sulphates, with alkaline bases; and it is well known these act an important part in vegetation. The influence of lime in their production is manifested by their appearing first at the place where the mortar and brick come into contact.

It will now be obvious to you, that in a mixture of clay with lime, all the conditions exist for the solution of the silicated clay, and the solubility of the alkaline silicates. The lime gradually dissolving in water charged with carbonic acid, acts like milk of lime upon the clay. This explains also the favorable influence which *marl* (by which term all those varieties of clay rich in lime are designated) exerts upon most kinds of soil. There are marly soils which surpass all others in fertility for all kinds of plants; but I believe marl in a burnt state must be far more effective, as well as other materials possessing a similar composition; as, for instance, those species of limestone which are adapted to the preparation of hydraulic cements—for these carry to the soil not only the alkaline bases useful to plants, but also silica in a state capable of assimilation.

The ashes of coals and lignite are also excellent means of ameliorating the soil, and they are used in many places for this purpose. The most suitable may be readily known by their property of forming a gelatinous mass when treated with acids, or by becoming, when mixed with cream of lime, like hydraulic lime—solid and hard as stone.

I have now, I trust, explained to your satifaction, that the mechanical operations of agriculture—the application of lime and chalk to lands, and the burning of clay—depend upon one and the same scientific principle: they are means of accelerating the decomposition of the alkaline clay silicates, in order to provide plants, at the beginning of a new vegetation, with certain inorganic matters indispensable for their nutrition.

LETTER XIV.

My Dear Sir:

I treated, in my last letter, of the means of improving the condition of the soil for agricultural purposes by mechanical operations and mineral agents. I have now to speak of the uses and effects of animal exuviæ, and vegetable matters or *manures*—properly so called.

In order to understand the nature of these, and the peculiarity of their influence upon our fields, it is highly important to keep in mind the source whence they are derived.

It is generally known, that if we deprive an animal of food, the weight of its body diminishes during every moment of its existence. If this abstinence is continued for some time, the diminution becomes apparent to the eye; all the fat of the body disappears, the muscles decrease in firmness and bulk, and, if the animal is allowed to die starved, scarcely any thing but skin, tendon, and bones, remain. This emaciation which occurs in a body otherwise healthy, demonstrates to us, that during the life of an animal every part of its living substance is undergoing a perpetual change; all its component parts, assuming the form of lifeless compounds, are thrown off by the skin, lungs, and urinary system, altered more or less by the secretory organs. This change in the living body is intimately connected with the process of respiration; it is, in truth, occasioned by the oxygen of the atmosphere in breathing, which combines with all the various matters within the body. At every inspiration a quantity of oxygen passes into the blood in the lungs, and unites with its elements; but although the weight of the oxygen thus daily entering into the body amounts to thirty-two or more ounces, yet the weight of the body is not thereby increased. Exactly as much oxygen as is imbibed in inspiration passes off in expiration, in the form of carbonic acid and water; so that with every breath the amount of carbon and hydrogen in the body is diminished. But the emaciation—the loss of weight by starvation—does not simply depend upon the separation of the carbon and hydrogen; but all the other substances which are in combination with these elements in the living tissues pass off in the secretions. The nitrogen undergoes a change, and is thrown out of the system by the kidneys. Their secretion, the urine, contains not only a compound rich in nitrogen, namely urea, but the sulphur of the tissues in the form of a sulphate, all the soluble salts of the blood and animal fluids, common salt, the phosphates, soda, and potash. The carbon and hydrogen of the blood of the muscular fibre, and of all the animal tissues which can undergo change, return into the *atmosphere*. The nitrogen, and all the soluble inorganic elements, are carried to the *earth* in the urine.

These changes take place in the healthy animal body during every moment of life; a waste and loss of substance proceeds continually; and if this loss is to be restored, and the original weight and substance repaired, an adequate supply of materials must be furnished whence the blood and wasted tissues may be regenerated. This supply is obtained from the food.

In an adult person in a normal or healthy condition, no sensible increase or decrease of weight occurs from day to day. In youth the weight of the body increases, while in old age it decreases. There can be no doubt that in the adult the food has exactly replaced the loss of substance: it has supplied just so much carbon, hydrogen, nitrogen, and other elements, as have passed through the skin, lungs, and urinary organs. In youth the supply is greater than the waste. Part of the elements of the food remain to augment the bulk of the body. In old age the waste is greater than the supply, and the body diminishes. It is unquestionable, that, with the exception of a certain quantity of carbon and hydrogen, which are secreted through the skin and lungs, we obtain, in the solid and fluid excrements of man and animals, all the elements of their food.

We obtain daily, in the form of urea, all the nitrogen taken in the food both of the young and the adult; and further, in the urine, the whole amount of the alkalies, soluble phosphates and sulphates contained in all the various aliments. In the solid excrements are found all those substances taken in the food which have undergone no alteration in the digestive organs, all indigestible matters, such as woody fibre, the green coloring matter of leaves (chlorophyle,) wax, &c.

Physiology teaches us that the process of nutrition in animals, that is, their increase of bulk, or the restoration of wasted parts, proceeds from the blood. In the stomach and intestines, therefore, all those substances in the food capable of conversion into blood are separated from its other constituents; in other words, during the passage of the food through the intestinal canal there is a constant absorption of its nitrogen, since only azotized substances are capable of conversion into blood; and, therefore, the solid excrements are destitute of that element, except only a small portion, in the constitution of that secretion which is formed to facilitate their passage. With the solid excrements, the phosphates of lime and magnesia, which were contained in the food and not assimilated, are carried off, these salts being insoluble in water, and therefore not entering the urine.

We may obtain a clear insight into the chemical constitution of the solid excrements without further investigation, by comparing the fæces of a dog with his food. We give that animal flesh and bones—substances rich in azotized matter—and we obtain, as the last product of its digestion, a perfectly white excrement, solid while moist, but becoming in the dry air a powder. This is the phosphate of lime of the bones, with scarcely one per cent. of foreign organic matter.

Thus we see that in the solid and fluid excrements of man and animals, all the nitrogen—in short, all the constituent ingredients of the consumed food, soluble and insoluble, are returned; and as food is primarily derived from the fields, we possess in those excrements all the ingredients which we have taken from it in the form of seeds, roots, or herbs.

One part of the crops employed for fattening sheep and cattle is consumed by man as animal food; another part is taken directly—as flour, potatoes, green vegetables, &c.; a third portion consists of vegetable refuse, and straw employed as litter. We can, it is obvious, get back all its constituent parts which have been withdrawn therefrom, as fruits, grain, and animals, in the fluid and solid excrements of man, and the bones, blood, and skins of the slaughtered animals. It depends upon ourselves to collect carefully all these scattered elements, and to restore the disturbed equilibrium of composition in the soil. We can calculate exactly how much and which of the component parts of the soil we export in a sheep or an ox, in a quarter of barley, wheat, or potatoes, and we can discover, from the known composition of the excrements of man and animals, how much we have to supply to restore what is lost to our fields.

If, however, we could procure from other sources, the substances which give to the exuviæ of man and animals their value in agriculture, we should not need the latter. It is quite indifferent for our purpose whether we supply the ammonia (the source of nitrogen) in the form of urine, or in that of a salt derived from coal-tar; whether we derive the phosphate of lime from bones, apatite, or fossil excrements (the coprolithes.)

The principal problem for agriculture is, how to replace those substances which have been taken from the soil, and which cannot be furnished by the atmosphere. If the manure supplies an imperfect compensation for this loss, the fertility of a field, or of a country, decreases; if, on the contrary, more are given to the fields, their fertility increases.

An importation of urine, or of solid excrements, from a foreign country, is equivalent to an importation of grain and cattle. In a certain time, the elements of those substances assume the form of grain, or of fodder, then become flesh and bones, enter into the human body, and return again day by day to the form they originally possessed.

The only real loss of elements we are unable to prevent is of the phosphates, and these, in accordance with the customs of all modern nations, are deposited in the grave. For the rest, every part of that enormous quantity of food which a man consumes during his lifetime (say in sixty or seventy years,) which was derived from the fields, can be obtained and returned to them. We know, with absolute certainty, that in the blood of a young or growing animal there remains a certain quantity of phosphate of lime and of the alkaline phosphates, to be stored up and minister to the growth of the bones and general bulk of the body, and that, with the exception of this very small quantity, we receive back, in the solid and fluid excrements, all the salts and alkaline bases, all the phosphate of lime and magnesia, and consequently all the inorganic elements which the animal consumes in its food.

We can thus ascertain precisely the quantity, quality, and composition of animal excrements, without the trouble of analysing them. If we give a horse daily 4½ pounds' weight of oats, and fifteen pounds of hay, and knowing that oats give four per cent. and hay nine per cent. of ashes, we can calculate that the daily excrements of the horse will contain twenty-one ounces of inorganic matter which was drawn from the fields. By analysis we can determine the exact relative amount of silica, of phosphates, and of alkalies, contained in the ashes of the oats and of the hay.

You will now understand that the constituents of the solid parts of animal excrements, and therefore their qualities as manure, must vary with the nature of the creature's food. If we feed a cow upon beetroot, or potatoes, without hay, straw, or grain, there will be no silica in her solid excrements, but there will be phosphate of lime and magnesia. Her fluid excrements will contain carbonate of potash and soda, together with compounds of the same bases with inorganic acids. In one word, we have in the fluid excrements, all the soluble parts of the ashes of the consumed food; and in the solid excrements, all those parts of the ashes which are insoluble in water.

If the food, after burning, leaves behind ashes containing soluble alkaline phosphates, as is the case with bread, seeds of all kinds, and flesh, we obtain from the animal by which they are consumed a urine holding in solution these phosphates. If, however, the ashes of food contain no alkaline phosphates, but abound in insoluble earthy phosphates, as hay, carrots, and potatoes, the urine will be free from alkaline phosphates, but the earthy phosphates will be found in the fæces. The urine of man, of carnivorous and graminivorous animals, contains alkaline phosphates; that of herbivorous animals is free from the salts.

The analysis of the excrements of man, of the piscivorous birds (as the *guano*,) of the horse, and of cattle, furnishes us with the precise knowledge of the salts they contain, and demonstrates, that in those excrements, we return to the fields the ashes of the plants which have served as food—the soluble and insoluble salts and earths indispensable to the development of cultivated plants, and which must be furnished to them by a fertile soil.

There can be no doubt that, in supplying these excrements to the soil, we return to it those constituents which the crops have removed from it, and we renew its capability of nourishing new crops: in one word, we restore the disturbed equilibrium; and, consequently, knowing that the elements of the food derived from the soil enter into the urine and solid excrements of the animals it nourishes, we can, with the greatest facility, determine the exact value of the different kinds of manure. Thus, the excrements of pigs, which we have fed with peas and potatoes, are principally suited for manuring crops of potatoes and peas. In feeding a cow upon hay and turnips, we obtain a manure containing the inorganic elements of grasses and turnips, and which is, therefore, preferable for manuring turnips. The excrement of pigeons contains the mineral elements of grain; that of rabbits, the elements of herbs and kitchen vegetables. The fluid and solid excrements of man, however, contain the mineral elements of grain and seeds in the greatest quantity.

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LETTER XV.

My Dear Sir:

You are now acquainted with my opinions respecting the effects of the application of mineral agents to our cultivated fields, and also the rationale of the influence of the various kinds of manure; you will, therefore, now readily understand what I have further to say of the sources whence the carbon and nitrogen, indispensable to the growth of plants, are derived.

The growth of forests, and the produce of meadows, demonstrate that an inexhaustible quantity of carbon is furnished for vegetation by the carbonic acid of the atmosphere.

We obtain from an equal surface of forest, or meadow-land, where the necessary mineral elements of the soil are present in a suitable state, and to which no carbonaceous matter whatever is furnished in manures, an amount of carbon, in the shape of wood and hay, quite equal, and ofttimes more than is produced by our fields, in grain, roots, and straw, upon which abundance of manure has been heaped.

It is perfectly obvious that the atmosphere must furnish to our cultivated fields as much carbonic acid, as it does to an equal surface of forest or meadow, and that the carbon of this carbonic acid is assimilated, or may be assimilated by the plants growing there, provided the conditions essential to its assimilation, and becoming a constituent element of vegetables, exist in the soil of these fields.

In many tropical countries the produce of the land in grain or roots, during the whole year, depends upon one rain in the spring. If this rain is deficient in quantity, or altogether wanting, the expectation of an abundant harvest is diminished or destroyed.

Now it cannot be the water merely which produces this enlivening and fertilizing effect observed, and which lasts for weeks and months. The plant receives, by means of this water, at the time of its first development, the alkalies, alkaline earths, and phosphates necessary to its organization. If these elements, which are necessary previous to its assimilation of atmospheric nourishment, be absent, its growth is retarded. In fact, the development of a plant is in a direct ratio to the amount of the matters it takes up from the soil. If, therefore, a soil is deficient in these mineral constituents, required by plants, they will not flourish even with an abundant supply of water.

The produce of carbon on a meadow, or an equal surface of forest land, is independent of a supply of carbonaceous manure, but it depends upon the presence of certain elements of the soil which in themselves contain no carbon, together with the existence of conditions under which their assimilation by plants can be effected. We increase the produce of our cultivated fields, in carbon, by a supply of lime, ashes, and marl, substances which cannot furnish carbon to the plants, and yet it is indisputable—being founded upon abundant experience—that in these substances we furnish to the fields elements which greatly increase the bulk of their produce, and consequently the amount of carbon.

If we admit these facts to be established, we can no longer doubt that a deficient produce of carbon, or in other words, the barrenness of a field does not depend upon carbonic acid, because we are able to increase the produce, to a certain degree, by a supply of substances which do not contain any carbon. The same source, when the meadow and the forest are furnished with carbon, is also open to our cultivated plants. The great object of agriculture, therefore, is to discover the means best adapted to enable these plants to assimilate the carbon of the atmosphere which exists in it as carbonic acid. In furnishing plants, therefore, with mineral elements, we give them the power to appropriate carbon from a source which is inexhaustible; while in the absence of these elements the most abundant supply of carbonic acid, or of decaying vegetable matter, would not increase the produce of a field.

With an adequate and equal supply of these essential mineral constituents in the soil, the amount of carbonic acid absorbed by a plant from the atmosphere in a given time is limited by the quantity which is brought into contact with its organs of absorption.

The withdrawal of carbonic acid from the atmosphere by the vegetable organism takes place chiefly through its leaves; this absorption requires the contact of the carbonic acid with their surface, or with the part of the plant by which it is absorbed.

The quantity of carbonic acid absorbed in a given time is in direct proportion to the surface of the leaves, and the amount of carbonic acid contained in the air; that is, two plants of the same kind, and the same extent of surface of absorption, in equal times and under equal conditions, absorb one and the same amount of carbon.

In an atmosphere containing a double proportion of carbonic acid, a plant absorbs, under the same condition, twice the quantity of carbon. Boussingault observed, that the leaves of the vine, enclosed in a vessel, withdrew all the carbonic acid from a current of air which was passed through it, however great its velocity. (Dumas Leçon, p. 23.) If, therefore, we supply double the quantity of carbonic acid to one plant, the extent of the surface of which is only half that of another living in ordinary atmospheric air, the former will obtain and appropriate as much carbon as the latter. Hence results the effects of humus, and all decaying organic substances, upon vegetation. If we suppose all the conditions for the absorption of carbonic acid present, a young plant will increase in mass, in a limited time, only in proportion to its absorbing surface; but if we create in the soil a new source of carbonic acid, by decaying vegetable substances, and the roots absorb in the same time three times as much carbonic acid from the soil as the leaves derive from the atmosphere, the plant will increase in weight fourfold. This fourfold increase extends to the leaves, buds, stalks, &c., and in the increased extent of surface, the plant acquires an increased power of absorbing nourishment from the air, which continues in action far beyond the time when its derivation of carbonic acid through the roots ceases. Humus, as a source of carbonic acid in cultivated lands, is not only useful as a means of increasing the quantity of carbon—an effect which in most cases may be very indifferent for agricultural purposes—but the mass of the plant having increased rapidly in a short time, space is obtained for the assimilation of the elements of the soil necessary for the formation of new leaves and branches.

Water evaporates incessantly from the surface of the young plant; its quantity is in direct proportion to the temperature and the extent of the surface. The numerous radical fibrilliæ replace, like so many pumps, the evaporated water; and so long as the soil is moist, or penetrated with water, the indispensable elements of the soil, dissolved in the water, are supplied to the plant. The water absorbed by the plant evaporating in an aëriform state, leaves the saline and other mineral constituents within it. The relative proportion of these elements taken up by a plant, is greater the more extensive the surface and more abundant the supply of water; where these are limited, the plant soon reaches its full growth, while if their supply is continued, a greater amount of elements necessary to enable it to appropriate atmospheric nourishment being obtained, its development proceeds much further. The quantity, or mass of seed produced, will correspond to the quantity of mineral constituents present in the plant. That plant, therefore, containing the most *alkaline phosphates* and *earthy salts*, will produce more or a greater weight of seeds than another which, in an equal time, has absorbed less of them. We consequently observe, in a hot summer, when a further supply of mineral ingredients from the soil ceases through want of water, that the height and strength of plants, as well as the development of their seeds, are in direct proportion to its absorption of the elementary parts of the soil in the preceding epochs of its growth.

The fertility of the year depends in general upon the temperature, and the moisture or dryness of the spring, if all the conditions necessary to the assimilation of the atmospheric nourishment be secured to our cultivated plants. The action of humus, then, as we have explained it above, is chiefly of value in gaining *time.* In agriculture, this must ever be taken into account; and in this respect *humus* is of importance in favoring the growth of vegetables, cabbages, &c.

But the ceralia, and plants grown for their roots, meet on our fields, in the remains of the preceding crop, with a quantity of decaying vegetable substances corresponding to their contents of mineral nutriment from the soil, and consequently with a quantity of carbonic acid adequate to their accelerated development in the spring. A further supply of carbonic acid, therefore, would be quite useless, without a corresponding increase of mineral ingredients.

From a morgen of good meadow land, two thousand five hundred pounds weight of hay, according to the best agriculturists, are obtained on an average. This amount is furnished without any supply of organic substances, without manure containing carbon or nitrogen. By irrigation, and the application of ashes or gypsum, double that amount will be grown. But assuming two thousand five hundred pounds weight of hay to be the maximum, we may calculate the amount of carbon and nitrogen derived from the atmosphere by the plants of meadows.

According to elementary analysis, hay, dried at a temperature of one hundred degrees of Reaumur, contains 45.8 per cent. of carbon, and 1.5 per cent. of nitrogen. Fourteen per cent. of water retained by the hay, dried at common temperatures, is driven off at one hundred degrees. Two thousand five hundred pounds weight of hay, therefore, corresponds to two thousand one hundred and fifty pounds, dried at one hundred degrees. This shows us, that nine hundred and eighty-four pounds of carbon, and 32.2 pounds weight of nitrogen, have been obtained in the produce of one morgen of meadow-land. Supposing that this nitrogen has been absorbed by the plants in the form of ammonia, the atmosphere contains 39.1 pounds weight of ammonia to every three thousand six hundred and forty pounds weight of carbonic acid (=984 carbon, or 27 per cent.); or, in other words, to every thousand pounds weight of carbonic acid, 10$\frac{7}{10}$ths pounds of ammonia, that is, to about $\frac{1}{100000}$th the weight of the air, or $\frac{1}{60000}$th of its volume.

For every hundred parts of carbonic acid absorbed by the surface of the leaves, the plant receives from the atmosphere somewhat more than one part of ammonia.

With every thousand pounds of carbon, we obtain—

From a meadow . . .	32$\frac{7}{10}$ths	pounds	of nitrogen.
From cultivated fields—			
In wheat . . .	21.5	"	"
Oats	22.3	"	"
Rye	15.2	"	"
Potatoes . . .	34.1	"	"
Beetroot . . .	39.1	"	"
Clover . . .	44	"	"
Peas	62	"	"

Boussingault obtained from his farm at Bechelbronn, in Alsace, in five years, in the shape of potatoes, wheat, clover, turnips, and oats, 8383 of carbon, and 250.7 nitrogen. In the following five years, as beetroot, wheat, clover, turnips, oats, and rye, 8,192 of carbon, and 284.2 of nitrogen. In a further course of six years, potatoes, wheat, clover, turnips, peas, and rye, 10,949 of carbon, 356.6 of nitrogen; in sixteen years, 27,424 carbon, 858.5 nitrogen: which gives, for every 1,000 carbon, 31.3 nitrogen.

From these interesting and unquestionable facts, we may deduce some conclusions of the highest importance in their application to agriculture.

1. We observe that the relative proportions of carbon and nitrogen, stand in a fixed relation to the surface of the leaves. Those plants in which all the nitrogen may be said to be concentrated in the seeds, as the ceralia, contain on the whole less nitrogen than the leguminous plants, peas and clover.

2. The produce of nitrogen on a meadow which receives no nitrogenized manure, is greater than that of a field of wheat which has been manured.

3. The produce of nitrogen in clover and peas, which agriculturists will acknowledge require no nitrogenized manure, is far greater than that of a potato or turnip field, which is abundantly supplied with such manures.

Lastly: and this is the most curious deduction to be derived from the above facts. If we plant potatoes, wheat, turnips, peas, and clover (plants containing potash, lime, and silex), upon the same land, three times manured, we gain in sixteen years, for a given quantity of carbon, the same proportion of nitrogen which we receive from a meadow which has received no nitrogenized manure.

On a morgen of meadow land, we obtain in plants, containing silex, lime, and potash, 984 carbon, 32.2 nitrogen. On a morgen of cultivated land, in an average of sixteen years, in plants containing the same mineral elements, silex, lime, and potash, 857 carbon, 26.8 nitrogen.

If we add the carbon and nitrogen of the leaves of the beetroot, and the stalks and leaves of the potatoes, which have not been taken into account, it still remains evident that the cultivated fields, notwithstanding the supply of carbonaceous and nitrogenized manures, produced no more carbon and nitrogen than an equal surface of meadow land supplied only with mineral elements.

What, then, is the rationale of the effect of manure—of the solid and fluid excrements of animals?

This question can now be satisfactorily answered: that effect is the restoration of the elementary constituents of the soil which have been gradually drawn from it in the shape of grain and cattle. If the land I am speaking of had not been manured during those sixteen years, not more than one half, or perhaps than one third part of the carbon and nitrogen would have been produced. We owe it to the animal excrements, that it equalled in production the meadow-land, and this, because they restored the mineral ingredients of the soil removed by the crops. All that the supply of manure accomplished, was to prevent the land from becoming poorer in these, than the meadow which produces two thousand five hundred pounds of hay. We withdraw from the meadow in this hay as large an amount of mineral substances as we do in one harvest of grain, and we know that the fertility of the meadow is just as dependent upon the restoration of these ingredients to its soil, as the cultivated land is upon manures. Two meadows of equal surface, containing unequal quantities of inorganic elements of nourishment—other conditions being equal—are very unequally fertile; that which possesses most, furnishes most hay. If we do not restore to a meadow the withdrawn elements, its fertility decreases. But its fertility remains unimpaired, with a due supply of animal excrements, fluid and solid, and it not only remains the same, but may be increased by a supply of mineral substances alone, such as remain after the combustion of ligneous plants and other vegetables; namely, *ashes*. Ashes represent the whole nourishment which vegetables receive from the soil. By furnishing them in sufficient quantities to our meadows, we give to the plants growing on them the power of condensing and absorbing carbon and nitrogen by their surface. May not the effect of the solid and fluid excrements, which are the ashes of plants and grains, which have undergone combustion in the bodies of animals and of man, be dependent upon the same cause? Should not the fertility, resulting from their application, be altogether independent of the ammonia they contain? Would not their effect be precisely the same in promoting the fertility of cultivated plants, if we had evaporated the urine, and dried and burned the solid excrements? Surely the ceralia and leguminous plants which we cultivate must derive their carbon and nitrogen from the same source whence the graminea and leguminous plants of the meadows obtain them! No doubt can be entertained of their capability to do so.

In Virginia, upon the lowest calculation, twenty-two pounds weight of nitrogen were taken on the average, yearly, from every morgen of the wheat-fields. This would amount, in one hundred years, to two thousand two hundred pounds weight. If this were derived from the soil, every morgen of it must have contained the equivalent of one hundred and ten thousand pounds weight of animal excrements (assuming the latter, when dried, at the temperature of boiling water, to contain two per cent.).

In Hungary, as I remarked in a former letter, tobacco and wheat have been grown upon the same field for centuries, without any supply of nitrogenized manure. Is it possible that the nitrogen essential to, and entering into, the composition of these crops, could have been drawn from the soil?

Every year renews the foliage and fruits of our forests of beech, oaks, and chestnuts; the leaves, the acorns, the chestnuts, are rich in nitrogen; so are cocoa-nuts, bread-fruit, and other tropical productions. This nitrogen is not supplied by man. Can it, indeed, be derived from any other source than the atmosphere?

In whatever *form* the nitrogen supplied to plants may be contained in the atmosphere, in whatever state it may be when absorbed, from the atmosphere it must have been derived. Did not the fields of Virginia receive their nitrogen from the same source as wild plants?

Is the supply of nitrogen in the excrements of animals quite a matter of indifference, or do we receive back from our fields a quantity of the elements of blood corresponding to this supply?

The researches of Boussingault have solved this problem in the most satisfactory manner. If, in his grand experiments, the manure which he gave to his fields was in the same state, that is, dried at 110° in a vacuum, as it was when analysed, these fields received, in sixteen years, thirteen hundred pounds of nitrogen. But we know that by drying all the nitrogen escapes which is contained in solid animal excrements, as volatile carbonate of ammonia. In this calculation the nitrogen of the urine, which by decomposition is converted into carbonate of ammonia, has not been included. If we suppose it amounted to half as much as that in the dried excrements, this would make the quantity of nitrogen supplied to the fields one thousand nine hundred and fifty pounds.

In sixteen years, however, as we have seen, only one thousand five hundred and seventeen pounds of nitrogen was contained in their produce of grain, straw, roots, et cetera—that is, *far less* than was supplied in the manure; and in the same period, the same extent of surface of good meadow-land (one hectare=a Hessian morgen,) which received no nitrogen in manure, two thousand and sixty pounds of nitrogen.

It is well known that in Egypt, from the deficiency of wood, the excrement of animals is dried, and forms the principal fuel, and that the nitrogen from the soot of this excrement was, for many centuries, imported into Europe in the form of sal ammoniac, until a method of manufacturing this substance was discovered at the end of the last century by Gravenhorst of Brunswick. The fields in the Delta of the Nile are supplied with no other animal manure than the ashes of the burnt excrements, and yet they have been proverbially fertile from a period earlier than the first dawn of history, and that fertility continues to the present day as admirable as it was in the earliest times. These fields receive, every year, from the inundation of the Nile, a new soil, in its mud deposited over their surface, rich in those mineral elements which have been withdrawn by the crops of the previous harvest. The mud of the Nile contains as little nitrogen, as the mud derived from the Alps of Switzerland, which fertilises our fields after the inundations of the Rhine. If this fertilising mud owed this property to nitrogenised matters; what enormous beds of animal and vegetable exuviæ and remains ought to exist in the mountains of Africa, in heights extending beyond the limits of perpetual snow, where no bird, no animal finds food, from the absence of all vegetation?

Abundant evidence in support of the important truth we are discussing, may be derived from other well known facts. Thus, the trade of Holland in cheese may be adduced in proof and illustration thereof. We know that cheese is derived from the plants which serve as food for cows. The meadow-lands of Holland derive the nitrogen of cheese from the same source as with us; that is, the atmosphere. The milch cows of Holland remain day and night on the grazing-grounds, and therefore, in their fluid and solid excrements return directly to the soil all the salts and earthy elements of their food: a very insignificant quantity only is exported in the cheese. The fertility of these meadows can, therefore, be as little impaired as our own fields, to which we restore all the elements of the soil, as manure, which have been withdrawn in the crops. The only difference is, in Holland they remain on the field, while we collect them at home, and carry them, from time to time to the fields.

The nitrogen of the fluid and solid excrements of cows, is derived from the meadow-plants, which receive it from the atmosphere; the nitrogen of the cheese also must be drawn from the same source. The meadows of Holland have, in the lapse of centuries, produced millions of hundred weights of cheese. Thousands of hundred weights are annually exported, and yet the productiveness of the meadows is in no way diminished, although they never receive more nitrogen than they originally contained.

Nothing, then, can be more certain than the fact, that an exportation of nitrogenised products does not exhaust the fertility of a country; inasmuch as it is not the soil, but the atmosphere, which furnishes its vegetation with nitrogen. It follows, consequently, that we cannot increase the fertility of our fields by a supply of nitrogenised manure, or by salts of ammonia, but rather that their produce increases or diminishes in a direct ratio with the supply of mineral elements capable of assimilation. The formation of the constituent elements of blood—that is, of the nitrogenised principles in our cultivated plants—depends upon the presence of inorganic matters in the soil, without which no nitrogen can be assimilated, even when there

? [illegible]

is a most abundant supply. The ammonia contained in animal excrements exercises a favorable effect, inasmuch as it is accompanied by the other substances necessary to accomplish its transition into the elements of blood. If we supply ammonia associated with all the conditions necessary to its assimilation, it ministers to the nourishment of the plants; but if this artificial supply is not given, they can derive all the needed nitrogen from the atmosphere—a source, every loss from which is restored by the decomposition of the bodies of dead animals and the decay of plants. Ammonia certainly favors and accelerates the growth of plants in all soils, wherein all the conditions of its assimilation are united; but it is altogether without effect, as respects the production of the elements of blood where any of these conditions are wanting. We can suppose that *asparagin*, the active constituent of *asparagus*, the mucilaginous root of the *marsh-mallow*, the nitrogenised and sulphurous ingredients of *mustard-seed*, and of all cruciferous plants, may originate without the aid of the mineral elements of the soil. But if the principles of those vegetables, which serve as food, could be generated without the co-operation of the mineral elements of blood, without potash, soda, phosphate of soda, phosphate of lime, they would be useless to us and to herbivorous animals as food; they would not fulfil the purpose for which the wisdom of the Creator has destined them. In the absence of alkalies and the phosphates, no blood, no milk, no muscular fibre, can be formed. Without phosphate of lime, our horses, sheep, and cattle, would be without bones.

In the urine and in the solid excrements of animals we carry ammonia, and consequently nitrogen, to our cultivated plants, and this nitrogen is accompanied by all the mineral elements of food exactly in the same proportions in which both are contained in the plants which served as food to the animals, or, what is the same, in those proportions in which both can serve as nourishment to a new generation of plants, to which both are essential.

The effect of an artificial supply of ammonia, as a source of nitrogen, is, therefore, precisely analogous to that of humus as a source of carbonic acid—it is limited to a *gain of time;* that is, it accelerates the development of plants. This is of great importance, and should always be taken into account in gardening, especially in the treatment of the kitchen garden; and as much as possible in agriculture on a large scale, where the time occupied in the growth of the plants cultivated is of importance.

When we have exactly ascertained the quantity of ashes left after the combustion of cultivated plants which have grown upon all varieties of soil, and have obtained correct analysis of these ashes, we shall learn with certainty which of the constituent elements of the plants are constant and which are changeable, and we shall arrive at an exact knowledge of the sum of all the ingredients we withdraw from the soil in the different crops.

With this knowledge the farmer will be able to keep an exact record of the produce of his fields in harvest, like the account-book of a well regulated manufactory; and then, by a simple calculation, he can determine precisely the substances he must supply to each field, and the quantity of these, in order to restore their fertility. He will be able to express, in pounds weight, how much of this or that element he must give to the soil in order to augment its fertility for any given kind of plants.

These researches and experiments are the great *desideratum* of the present time. To the united efforts of the chemists of all countries we may confidently look for a solution of these great questions, and by the aid of enlightened agriculturists we shall arrive at a rational system of gardening, horticulture, and agriculture, applicable to every country and all kinds of soil, and which will be based upon the immutable foundation of observed facts and philosophical inductions.

LETTER XVI.

MY DEAR SIR:

My recent researches into the constituent ingredients of our cultivated fields have led me to the conclusion that, of all the elements furnished to plants by the soil and ministering to their nourishment, the phosphate of lime, or, rather, the phosphates generally, must be regarded as the most important.

In order to furnish you with a clear idea of the importance of the phosphates, it may be sufficient to remind you of the fact, that the blood of man and animals, beside common salt, always contains alkaline and earthy phosphates. If we burn blood and examine the ashes which remain, we find certain parts of them soluble in water, and others insoluble. The soluble parts are, common salt and alkaline phosphates; the insoluble consist of phosphate of lime, phosphate of magnesia, and oxide of iron.

These mineral ingredients of the blood—without the presence of which in the food the formation of blood is impossible—both man and animals derive, either immediately or mediately, through other animals, from vegetable substances used as food; they had been constituents of vegetables, they had been parts of the soil upon which the vegetable substances were developed.

If we compare the amount of the phosphates in different vegetable substances with each other, we discover a great variety, while there is scarcely any ashes of plants altogether devoid of them, and those parts of plants which experience has taught us are the most nutritious, contain the largest proportion. To these belong all seeds and grain, especially the varieties of bread-corn, peas, beans, and lentils.

It is a most curious fact that, if we incinerate grain or its flour, peas, beans, and lentils, we obtain ashes, which are distinguished from the ashes of all other parts of vegetables by the absence of *alkaline carbonates*. The ashes of these seeds, when recently prepared, do not effervesce with acids; their soluble ingredients consist solely of alkaline phosphates, the insoluble parts of phosphate of lime, phosphate of magnesia, and oxide of iron; consequently, of the very same salts which are contained in blood, and which are absolutely indispensable to its formation. We are thus brought to the further indisputable conclusion, that no seed suitable to become food for man and animals can be formed in any plant without the presence and co-operation of the phosphates. A field, in which phosphate of lime, or the alkaline phosphates form no part of the soil, is totally incapable of producing grain, peas, or beans.

An enormous quantity of these substances, indispensable to the nourishment of plants, is annually withdrawn from the soil and carried into great towns, in the shape of flour, cattle, et cetera. It is certain that this incessant removal of the phosphates must tend to exhaust the land and diminish its capability of producing grain. The fields of Great Britain are in a state of progressive exhaustion from this cause, as is proved by the rapid extension of the cultivation of turnips and mangel-wurzel—plants which contain the least amount of the phosphates, and therefore require the smallest quantity for their development. These roots contain 80° to 92° per cent. of water. Their great bulk makes the amount of produce fallacious, as respects their adaptation to the food of animals, inasmuch as their contents of the ingredients of the blood—that is, of substances which can be transformed into flesh—stands in a direct ratio to their amount of phosphates, without which neither blood nor flesh can be formed.

Our fields will become more and more deficient in these essential ingredients of food, in all localities where custom and habits do not admit the collection of the fluid and solid excrements of man, and their application to the purposes of agriculture. In a former letter I showed you how great a waste of phosphates is unavoidable in England, and referred to the well known fact, that the importation of bones restored in a most admirable manner the fertility of the fields exhausted from this cause. In the year 1827, the importation of bones for manure amounted to forty thousand tons, and Huskisson estimated their value to be from one hundred thousand to two hundred thousand pounds sterling. The importation is still greater at present, but it is far from being sufficient to supply the waste.

Another proof of the efficacy of the phosphates in restoring fertility to exhausted land is afforded by the use of the *guano*—a manure which, although of recent introduction into England, has found such general and extensive application.

We believe that the importation of one hundred weight of *guano* is equivalent to the importation of eight hundred weight of wheat—the hundred weight of guano assumes, in a time which can be accurately estimated, the form of a quantity of food corresponding to eight hundred weight of wheat. The same estimate is applicable in the valuation of bones.

If it were possible to restore to the soil of England and Scotland the phosphates which during the last fifty years have been carried to the sea by the Thames and the Clyde, it would be equivalent to manuring with millions of hundred weights of bones, and the produce of the land would increase one-third, or, perhaps, double itself, in five or ten years.

We cannot doubt that the same result would follow, if the price of the guano admitted the application of a quantity to the surface of the fields, containing as much of the phosphates as have been withdrawn from them in the same period.

If a rich and cheap source of phosphate of lime and the alkaline phosphates were open to England, there can be no question that the importation of foreign corn might be altogether dispensed with after a short time. For these materials England is at present dependent upon foreign countries, and the high price of guano and of bones prevents their general application, and in sufficient quantity. Every year the trade in these substances must decrease, or their price will rise as the demand for them increases.

According to these premises, it cannot be disputed that the annual expense of Great Britain for the importation of bones and guano is equivalent to a duty on corn—with this difference only, that the amount is paid to foreigners in money.

To restore the disturbed equilibrium of constitution of the soil—to fertilize her fields—England requires an enormous supply of animal excrements; and it must, therefore, excite considerable interest to learn that she possesses, beneath her soil, beds of fossil *guano*, strata of animal excrements, in a state which will probably allow of their being employed as a manure at a very small expense.

The coprolithes, discovered by Dr. Buckland (a discovery of the highest interest to Geology,) are these excrements; and it seems extremely probable that in these strata England possesses the means of supplying the place of recent bones, and, therefore, the principal conditions of improving agriculture—of restoring and exalting the fertility of her fields.

In the autumn of 1842, Dr. Buckland pointed out to me a bed of coprolithes in the neighborhood of Clifton, from half to one foot thick, enclosed in a limestone formation, extending as a brown stripe in the rocks, for miles along the banks of the Severn. The limestone marl, of Lyme Regis, consists, for the most part, of one-fourth part of fossil excrements and bones. The same are abundant in the lias of Bath, Eastern and Broadway Hill, near Eversham. Dr. Buckland mentions beds, several miles in extent, the substance of which consists, in many places, of a fourth part of coprolithes.

Pieces of the limestone rock of Clifton, near Bristol, which is rich in coprolithes and organic remains, fragments of bones, teeth, &c., were subjected to analysis, and were found to contain above eighteen per cent. of phosphate of lime. If this limestone is burned, and brought in that state to the fields, it must be a perfect substitute for bones, the efficacy of which, as a manure, does not depend, as has been generally but erroneously supposed, upon the nitrogenised matter which they contain, but on their phosphate of lime.

The osseous breccia found in many parts of England deserves especial attention, as it is highly probable that in a short time it will become an important article of commerce.

What a curious and interesting subject for contemplation! In the remains of an extinct *animal* world, England is to find the means of increasing her wealth in agricultural produce, as she has already found the great support of her manufacturing industry in fossil fuel—the preserved matter of primeval forests—the remains of a *vegetable* world. May this expectation be realized! and may her excellent population be thus redeemed from poverty and misery.

THE END.

End of
Volume

Volume:
4

RESEARCHES ON THE

MOTION OF THE

JUICES IN THE ANIMAL BODY;

AND THE EFFECT OF EVAPORATION IN PLANTS.

TOGETHER WITH AN ACCOUNT OF THE

ORIGIN OF THE POTATO DISEASE;

WITH FULL AND INGENIOUS DIRECTIONS FOR THE PROTECTION
AND ENTIRE PREVENTION OF THE

POTATO PLANT AGAINST ALL DISEASES.

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ILLUSTRATED WITH FIFTEEN FINE ENGRAVINGS.

EDITED FROM THE MANUSCRIPT OF THE AUTHOR, BY
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PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF EDINBURG.

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EDITOR'S PREFACE.

In the Editor's Preface to Baron Liebig's "Researches on the Chemistry of Food," in which the Author gave the results of his investigation into the constituents of the juice of the flesh, I mentioned that Baron Liebig had been led to study the subject of Endosmosis experimentally. The results of this investigation are contained in the following pages; and the reader will, I trust, be satisfied that the motions of the animal juices depend on something more than mere Endosmosis or Exosmosis, and that the pressure of the atmosphere, as well as its hygrometric state, by influencing the transpiration from the skin and lungs, are essentially concerned in producing these motions. At the same time, the present work is to be regarded, not as exhausting the subject, but, on the contrary, as only pointing out the direction in which inquiry is likely to lead to the most valuable results.

While it is proved that the mechanical causes of pressure and evaporation, and the chemical composition of the fluids and membranes, have a more direct, constant, and essential influence on the motion of the animal fluids, and, consequently, on the state of the health, than has been usually supposed, it is evident that very much remains to be done in tracing that influence under the ever varying circumstances of the animal body, and in applying the knowledge thus acquired to the purposes of hygiene and therapeutics. But it is equally obvious, that the above-mentioned mechanical and chemical causes are not alone sufficient to explain the phenomena of animal life, since they are present equally in a dead and in a living body; so that while every advance in physiology enables us to explain more facts on chemical and mechanical principles, something always remains, which, for the present, is beyond our reach, and which may forever remain so. However this may be, the facts established in this and in the preceding work of the Author have very materially extended the application of the well-known laws of physics and of chemistry to physiology, and have also furnished a number of the most beautiful instances of that infinitely wise, but exquisitely simple adaptation of means to ends, which characterizes all the works of the omnipotent Creator; but which is no where more admirably displayed, than in the arrangements, imperfectly known as they hitherto are, by which life is maintained.

In connection with the Author's remarks on the effects of evaporation in plants, and the consequences of its suppression, and with his opinions as to the origin of the potato disease, I beg to refer the reader to the Appendix for a very ingenious and apparently well founded plan for the protection of the potato plant against the terrible scourge under which it has lately suffered. The views of Dr. Klotzsch, the author of this plan, as to the nature of the disease, coincide remarkably with those of Baron Liebig, as explained in the present work.

WILLIAM GREGORY.

EDINBURGH, 3*d* *March*, 1852.

PREFACE.

THE present little work contains a series of experiments the object of which is to ascertain the law according to which the mixture of two liquids, separated by a membrane, takes place. The reader will, I trust, perceive in these researches an effort to attain, experimentally, to a more exact expression of the conditions under which the apparatus of the circulation acquires all the properties of an apparatus of absorption.

In the course of this investigation, the more intimate study of the phenomena of Endosmosis impressed on me the conviction that, in the organism of many classes of animals, causes of the motion of the juices were in operation, far more powerful than that to which the name of Endosmosis has been given.

The passage of the digested food through the membranes of the intestinal canal, and its entrance into the blood; the passage of the nutrient fluid outwards from the blood vessels, and its motion towards the parts where its constituents acquire vital properties,—these two fundamental phenomena of organic life cannot be explained by a simple law of mixture.

The Experiments described in the following pages will, perhaps, be found to justify the conviction that these organic movements depend on the transpiration and on the atmospheric pressure.

The importance of the transpiration for the normal vital process has, indeed, been acknowledged by physicians ever since Medicine had an existence; but the law of the dependance of the state of health on the quality of the atmosphere, on its barometric pressure, and its hygrometric condition, has been hitherto but little investigated.

By the researches contained in my examination of the constituents of the juice of flesh, as well as by those described in the present work, the completion of the second part of my Animal Chemistry has been delayed; but I did not consider myself justified in continuing that work until I had examined the questions suggested by, and connected with those researches.

DR. JUSTUS LIEBIG.

GIESSEN, *February*, 1852.

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ON

THE PHENOMENA

ACCOMPANYING

THE MIXTURE OF TWO LIQUIDS

SEPARATED BY

A MEMBRANE.

THE constituents of the food, which have assumed a soluble form in the alimentary canal, are thereby endowed with the property of yielding to the influence of every cause which, in acting on them, tends to change their place or the position which they occupy.* They are conveyed into the blood vessels, and from thence are distributed to all parts of the body.

The movement and distribution of these fluids, and of all the substances dissolved in them, exclusive of the mechanical cause of the contraction of the heart, by which the circulation of the blood is effected, depend, 1, on the permeability of the walls of all vessels to these fluids; 2, on the pressure of the atmosphere; and 3, on the chemical attraction which the various fluids of the body exert on each other.† The motion of all fluids in the body is effected by means of water: and all parts of the animal system contain, in the normal state, a certain amount of water.

Animal membranes, tendons, muscular fibres, cartilaginous ligaments, the yellow ligaments of the vertebral column, the cornea, transparent and opaque, &c., all contain, in the fresh state, more than half their weight of water, which they lose, more or less completely, in dry air.‡

On the presence of this water depend several of their physical properties. The fresh, opaque, milk-white cartilagesof the ear become, when dried, translucent, and acquire a reddish yellow color. Tendons, when fresh, are in a high degree flexible and elastic and possess a silky lustre, which they lose when dried. By the same loss of water they become, further, hard, horny, and translucent, and when bent, split into whitish bundles of fibres. The sclerotic coat is milk-white when fresh, and becomes transparent by desiccation.

When these substances, after having lost, by drying, a part of the properties which they possess in the fresh state, are again placed in contact with pure water, they take up, in 24 hours, the whole original amount of water, and recover perfectly those properties which they had lost. The opaque cornea, or sclerotic coat, which had become transparent by desiccation, again becomes milk-white, while the transparent cornea, which had been rendered opaque by drying, now becomes again transparent. The tendons, which, when dried, had become horny, hard, and translucent, now again become flexible and elastic, and recover their silky lustre. The fibrine and the cartilages of the ear, which desiccation had rendered horny and transparent, again become milk-white and elastic.

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* The food becomes soluble, and the fluids of the body are sent to all parts.

† General causes of their motion.

‡ Relation of animal tissues to water.

The power which the solids of the animal body possess of taking up water into their substance, and of being penetrable to water, extends to all fluids allied to water, that is miscible with it.[*] In the dried state, the animal solids take up fluids of the most diverse natures, such as fatty and volatile oils, ether, bisulphuret of carbon, &c. This permeability to fluids is possessed by animal tissues in common with all porous bodies; and no doubt can be entertained, that this property is determined by the same cause which produces the ascent of fluids in narrow tubes, or in the pores of a sponge; phenomena, which we are accustomed to include under the name of capillary action.

One condition, essential to the permeability of porous bodies for fluids (or their power of absorption), is their capability of being moistened; or the attraction which the particles of the fluid and the walls of the pores or tubes have towards each other.[†] A second condition is the attraction which one particle of the fluid has to another. We have no means of estimating the absolute size of the particles or molecules of a fluid, such as water, but they are certainly infinitely smaller than the measurable diameter of a tube, or of the pores of a porous body. It is obvious, therefore, that in the interior of a capillary tube or pore, filled with a fluid, only a certain number of the fluid molecules are in contact with the walls of the tube, and attracted by them; while in the middle of the tube, and from thence towards its parietes, fluid molecules must exist which only retain their place in virtue of the attraction which the molecules, attracted by the parietes, exert on those not so attracted; that is, by the cohesive attraction of the fluid.

Liquids flow out of capillary tubes, which are filled with them, only when some other force or cause acts, because capillary attraction cannot produce motion beyond the limits of the solid body which determines the capillary action.

The penetration of a fluid into the pores of a porous body, is the result of capillary attraction; its expulsion can be affected by a mechanical pressure; and may be accelerated by increasing this pressure, and by all such causes as diminish the mutual attraction of the fluid molecules, or the attraction of the walls of the pores for those molecules. The condition most favorable to the passage of a fluid through the pores of a porous substance under pressure, is when one fluid molecule can be displaced so as to glide away over another.

The slightest pressure suffices to expel the displaceable particles of water from a sponge; a higher pressure is required to express the same fluid from bibulous paper; and a pressure much higher still is necessary in order to cause water to flow out of moist wood.[‡] We may form some idea of the force with which porous organic substances, such as dry wood, absorb and retain water, if we remember, that by inserting of wedges of dry wood in proper cuts, and subsequently moistening them, rocks may be split and fractured.

When we compare with the properties just enumerated, which belong to all porous bodies, those properties which are observed in animal substances under the same circumstances, it appears plainly that these animal substances have pores in certain directions;[§] although these openings are so minute that they are not, in the case of most tissues, perceptible, even with the aid of the best microscopes.

It has been mentioned that tendons, ligaments, cartilages, &c., contain, in the fresh state, a certain amount of water, which, according to all experiments made on the subject, is invariable; and that several of their properties depend on the presence of this water.[‖] (CHEVREUL.) When these substances, wrapped in bibulous paper, are subjected to a powerful pressure, a certain proportion of this water is expelled. Fresh and flexible vessels lose, in this way, 37.6 per cent., and the yellow ligaments of the vertebræ lose 35 per cent. of water. This property, namely, that of losing water under pressure, is only found in porous substances. It is obvious that by pressure, that is, by diminution of the size of the pores, only that portion of water can be pressed out which is not retained by chemical attraction.[*] It is in the highest degree worthy of notice, that this water, not chemically combined, seems to have the greatest share in the properties which these animal substances possess in the fresh state, for the pressed tendons and yellow ligaments become transparent; the former lose their flexibilty, the latter their elasticity; and if laid in water, they recover these properties perfectly. In the pores of a porous substance, the fluid molecules are retained by two kinds of attraction, namely, by the affinity which is exerted between the walls of the pores and the molecules of the fluid, and by the cohesion which acts between the molecules of the fluid itself. It would appear as if the molecules of water were thus brought into different states, and this seems to be the cause of the differences observed in the properties of these animal substances when they contain different proportions of water.

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[*] The tissues absorb other fluids.

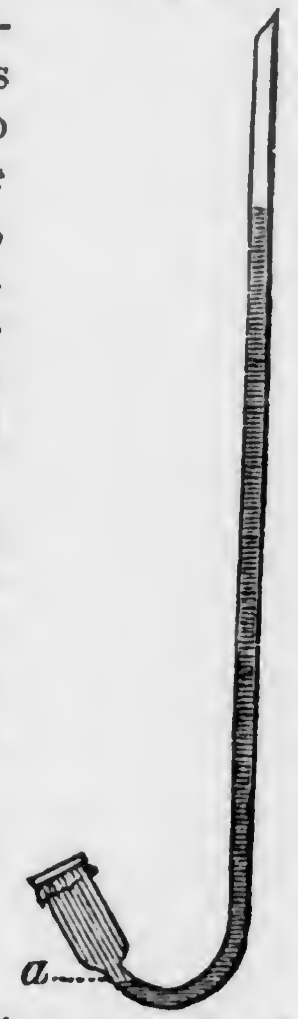
[†] The moistening of porous bodies.

[‡] Prodigious force with which porous bodies absorb water.

[§] Animal tissues are porous.

[‖] Amount of water expelled by pressure from tissues.

Fig. 1.



[†] If the wide opening of the tube, Fig. 1, be tied over with a portion of bladder, and water poured into the wide part of the tube, as far as the mark *a*, we shall find that, when mercury is poured into the upright narrow part of the tube, to a certain height, the whole external surface of the bladder becomes covered with minute drops, which, if the column of mercury be made a few lines higher, unite, so as to form large drops. These continue to flow out uninterruptedly, if mercury be added, so as to keep the column at the same height, till at last the wide part of the tube is emptied of water and filled with mercury.

Solution of salt, fat oil, alcohol, &c., behave exactly as water does; under a certain pressure these fluids pass through an animal membrane, just as water does through a paper filter.

The pressure required to cause these liquids to flow through the pores of animal textures depends on the thickness of the membrane, as well as on the chemical nature of the different liquids.

Through ox-bladder, $\frac{1}{10}$th of a line ($\frac{1}{120}$th of an inch) thick, water flows under a pressure of 12 inches of mercury.[‡] A saturated solution of sea salt requires from 18 to 20 inches; and oil (marrow oil) only flows out under a pressure of 34 inches of mercury.

When the membrane used is the peritoneum of the ox, $\frac{1}{20}$th of a line, ($\frac{1}{240}$th of an inch) in thickness, water is forced through it by 8 to 10 inches, brine by 12 to 16 inches, oil by 22 to 24 inches, and alcohol by 36 to 40 inches of mercury.

The same membrane from the calf, $\frac{1}{666}$th of a line ($\frac{1}{1992}$d of an inch) in thickness, allows water to pass through under the pressure of a column of water 4 inches high; brine passes under a pressure of 8 to 10 inches of brine, and oil under a pressure of 3 inches of mercury.

In making experiments of this nature, we observe that, after they have continued for some time, the pressure required to force the liquid through the membrane does not continue equal. If during the first 6 hours a pressure of 12 inches of mercury were necessary, we often find that after 24 or 36 hours, 8, or even 6 inches will suffice to produce the same effect, obviously because by long-continued contact with water, the membrane undergoes an alteration, in consequence of which the pores are widened.

From these experiments it appears, that the power of a liquid to filter through an animal membrane bears no relation to the mobility of its particles;[§] for under a pressure which causes water, brine, or oil to pass through, the far more mobile alcohol does not pass.

The capacity of the animal membrane for being moistened by, and its power of absorbing, the liquid, have a certain share in producing the result of its filtration through the membrane.[‖]

The following table will show this fact:

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[*] The portion of water not chemically combined, has the greatest share in the properties of the tissues.

[†] Pressure required to cause water and any other liquids to pass through membranes.

[‡] The pressure varies with different liquids.

[§] The passage of liquids through membranes not in proportion to their fluidity.

[‖] The absorbent power of the membrane for the liquid has a share in the effect.

100 parts, by weight, of dry ox-bladder, take up in 24 hours,—

of pure water	268	volumes
,, saturated solution of sea salt (brine)	133	,,
,, alcohol of 84 per cent.	38	,,
,, oil of marrow*	17	,,

100 parts, by weight, of ox-bladder, take up in 48 hours,—

of pure water					310	parts by weight
of a mixture of	⅓	water and	⅔	brine	219	,,
,, ,,	½	,,	½		235	,,
,, ,,	⅔	,,	⅓		288	,,
,, ,,	½	alcohol	½		60	,,
,, ,,	⅓	,,	⅔		181	,,
,, ,,	¼	,,	¾		290	,,

100 parts of dry pig's bladder take up in 24 hours,—

of pure water	356	volumes
,, brine	159	,,
,, oil of marrow	14	,,

From these experiments it appears that the absorptive power of animal membranes for different liquids is very different. Of all liquids, pure water is taken up in the largest quantity; and the absorptive power for solution of salt diminishes in a certain ratio as the proportion of salt increases. A similar relation holds between the membranes and alcohol; for a mixture of alcohol and water is taken up more abundantly the less alcohol it contains.[1]

(1) In regard to this property, membranes differ in no respect from other animal textures, as was long ago proved by Chevreul. This distinguished philosopher found that the following substances absorbed, in 24 hours, of water, brine, and oil,—

	Cubic Centimetres Water.	C. C. Brine.	C. C. Oil.
100 grammes of cartilage of the ear	231	125	—
100 ,, tendons	178	114	8.6
100 ,, yellow ligaments of spine	148	30	7.2
100 ,, cornea	461	370	9.1
100 ,, cartilaginous ligaments	319	—	3.2
100 ,, dry fibrine absorbed	301 of water and 148 of alcohol of 69 per cent. (Liebig.)		
100 ,, ,, ,,	184 parts by weight or 154 by volume of brine.		

Animal membranes do not acquire, by absorbing alcohol or oil, those properties which they exhibit when saturated with water.† A dried bladder continues hard and brittle in alcohol and oil; its flexibility is in no degree increased by absorbing these liquids. When tendons, ligaments (CHEVREUL,) the yellow ligaments of the spine, or bladder, saturated with oil, are placed in water, the oil is completely expelled, and they take up as much water as if they had not previously been in contact with oil.

It has been mentioned, that 100 parts of animal membrane (dry ox-bladder) absorb in 24 hours 268, in 48 hours 310 volumes of water, and only 133 of saturated solution of salt. It follows, of course, that when the bladder, saturated with water by 48 hours' contact, and well dried in bibulous paper, without pressure, to remove superfluous water, is strewed with salt, there is formed, at all points where salt comes in contact with the water filling the open pores, a saturated solution of salt, the salt contained in which diffuses itself equally in the water of the bladder. Of the 310 volumes of water which become thus saturated with salt, only 133 volumes are retained in the bladder; and in consequence of this diminution of the absorbent power of the bladder for the brine, 177 volumes of liquid are expelled, and run off in drops from the surface of the bladder.

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* Absorption of different liquids.

† Effects of oil, salt, &c., on membranes when dry, and when in the moist state.

Membranes, fibrine, or a mass of flesh, behave exactly in a similar manner when in contact with alcohol. If placed in alcohol in the fresh state, that is, when they are thoroughly charged with water, there are formed, at all points where water and alcohol meet, mixtures of the two, and as the animal texture absorbs much less of an alcoholic mixture than of pure water, more water is, of course, expelled, than alcohol taken up.

9·17 grammes of bladder, fresh, that is saturated with water (in which are contained 6·95 grammes of water, and 2·22 of dry substance,) when placed in 40 cubic centimetres of alcohol, weigh, at the end of 24 hours, 4·73 grammes, and have, consequently, lost 4·44 grammes.* In the 4·73 grammes which remain, are 2·22 grammes of dry bladder, and, of course, 2·51 grammes of liquid. If we assume that this liquid has the same composition as the surrounding mixture (which is found to contain 84 parts of alcohol to 16 of water,) it will consist of 2·11 grammes of alcohol and 0·40 of water; and consequently, of the 6·95 grammes of water originally present, 6·45 grammes have been expelled, and replaced by 2·11 grammes of alcohol. For 1 volume of alcohol, therefore, retained by the bladder, rather more than 3 volumes of water have been expelled from it.

† Since, in this case, so much more water is expelled than is taken up of alcohol, the first result is a shrinking of the animal substance.(1)

If the bladder could take up or absorb equal volumes of brine and water, or of alcohol and water, then when the fresh bladder was strewed with salt, or laid in alcohol, the volume of the absorbed liquid would be unaltered, and an equal volume of saline solution, or of diluted alcohol, would be retained by the animal tissue. But since the absorbent power of the tissue for water is diminished by the addition of salt, or of alcohol, it follows plainly, that a certain quantity of water must be expelled as soon as its character is changed by the addition of one of these substances.

The relation of bladder, fibrine, and other animal substances, when saturated with water, to alcohol and brine, proves, that the shrinking (diminution of volume) of these tissues does not depend on a simple abstraction of water in virtue of the affinity of alcohol and of salt for that liquid; for it is quite certain that the attraction of alcohol to water, and that of water to alcohol, are respectively equal.‡ The attraction of the water within the tissue for the alcohol without, is just as strong as the power of the alcohol without to combine with the water within. Less alcohol is taken up, and more water given out, because the animal tissue has less attraction for the mixture of alcohol and water than for pure water alone. The alcohol without becomes diluted, the water within becomes mixed with a certain proportion of alcohol, and this exchange is only arrested when the attraction of the water for the animal tissue, and its attraction for alcohol, come to counterpoise each other.

If we regard a piece of skin, or bladder, or fibrine as formed of a system of capillary tubes, the pores or minute tubes are, in the fresh state, filled with a watery liquid, which is prevented from flowing out by capillary attraction.

But the liquid contained in these capillary tubes flows out of them as soon as its composition is altered by the addition of salt, alcohol, or other bodies.

(1) Fibrine and other animal matters exhibit results quite similar to those obtained with bladder. 26·02 grammes of fibrine saturated with water (containing 6·48 grammes of dry fibrine and 19·54 of water) were reduced, in 45 grammes of absolute alcohol, to 16·12 grammes, losing, therefore, 9·90 grammes. Admitting the absorbed liquid to have the composition of the unabsorbed residue (70 per cent. of alcohol,) it appears, that for 1 volume of alcohol absorbed by fibrine rather more than 2½ volumes of water are separated.

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* Amount of water expelled from bladder by alcohol.

† Moist membranes shrink when strewed with salt, or placed in alcohol.

‡ The cause of this is the less affinity of the tissue for alcohol, &c., than for water.

If we lay together, one over the other, two portions of bladder, saturated with solution of salt of sp. g. 1·204, and over the upper one another piece of bladder of equal size, saturated with water, and if we allow them to remain thus, without pressure, we find, after some minutes, when the two pieces saturated with solution of salt are separated, that drops of saline solution appear between them, of which no trace could previously be perceived. If the piece of bladder saturated with water contained 5 volumes of water, and the next piece 3 volumes of saline solution, there must be produced, by the mixture of both, 8 volumes of diluted saline solution, of which each piece of bladder must contain one half, or 4 volumes, if the absorbent power of the portion saturated with the original saline solution were increased by the addition of water in the same ratio as the absorbent power of the portion saturated with water was diminished by the addition of salt. The saline liquid would have given up 1½ volume of saline solution to the other, and would have received from it 2½ volumes of water. In this case, the mixture in the two upper pieces of bladder would occupy the same space which its constituents, water and saline solution, occupied in each singly. But the efflux of the liquid towards the third or lowest piece of bladder saturated with saline solution, proves, that the two upper pieces retain a smaller volume of the mixture newly formed in their pores, than the one piece absorbed of water alone, and the other of saline solution alone. The power of retaining water is diminished by the addition of salt to the bladder saturated with water; liquid is expelled; but by the addition of this water to the bladder moistened with saline solution, the absorbent power of this piece of bladder is increased, not in the same ratio according to which the proportion of salt is diminished, but in a less ratio.

The experiments above described show that the attraction of the porous substances for the water which they have absorbed does not prevent the mixture of this water with other liquids.

The permeability of animal tissues to liquids of every kind, and the miscibility of the absorbed liquids with others which are brought in contact with the tissues, may be demonstrated by the simplest experiments.[*]

If we moisten one side of a thin membrane with ferrocyanide, of potassium, and the opposite side with chloride of iron in solution, we perceive in the substance of the membrane a spot of Prussian blue immediately deposited. (JOH. MULLER.)

All fluids which, when brought together, suffer a change in their nature or in their properties, exhibit, when only separated by an animal membrane, exactly analogous results; they mix in the pores of the membrane, and the decomposition commences in its substance.

If we tie up one end of a cylindrical glass tube with bladder, and fill it to the height of 3 or 4 inches with water or strong brine, neither the water nor the brine flows out through the pores of the bladder under this slight pressure.

But if we leave the tube containing brine exposed to evaporation in the air, the side of the bladder exposed to the air is soon covered with crystals of salt, which gradually increase, so as to form a thick crust.[†] It is obvious that the pores of the bladder become fluid with brine; that, on the side exposed to the air, the water evaporates; its place is supplied by fresh brine, and the dissolved salt is deposited at the external minute openings of the pores, in the form of crystals. If the tube be filled originally with dilute saline solution, the crust of salt is not formed on the outer surface of the bladder until the solution in the tube has reached, by evaporation, the maximum of saturation. Before this takes place, we can perceive in the tube, if we set the liquid in motion, two strata, a heavier and a lighter, the latter swimming on the former. When these strata can no longer be observed, the liquid is in every part saturated with salt; and now, by further evaporation, crystals are deposited on the outer surface of the bladder. This last circumstance proves that the amount of salt in the liquid is uniformly distributed from below upwards, from the specifically heavier to the specifically lighter part.

If we immerse the tube closed with bladder, and filled with saline solution, in pure water, the latter acquires the property of precipitating nitrate of silver, even

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[*] Animal tissues are permeable to liquids of every kind, which act on each other in the substance of the tissues.

[†] Deposition of salt on the outside of bladder from brine on the inside.

when the contact has lasted only the fraction of a second.[*] The brine filling the open pores of the membrane mixes with the pure water, and the latter acquires a certain quantity of salt.

In like manner, the pure water acquires a saline impregnation, when it is placed in the tube instead of brine, and the outer surface of the bladder is placed in contact with solution of salt.

When the tube, closed with bladder, and filled with brine, is left for a long time with the closed end immersed in pure water, the amount of salt in the latter increases, while that of the brine diminishes, till at last the two liquids, separated by the bladder, contain the same relative proportions of salt and water.

If the liquid in the tube contain, dissolved, other substances which give to it properties different from those of pure water, and if these solutions be miscible with water, the mixture of them with the water takes place exactly as in the case of brine.[†] This is true of saline solutions of every kind; of bile, milk, urine, serum of blood, syrup, solution of gum, &c., on the one side, and pure water on the other. The concentrated liquid loses, the water or diluted liquid gains, in regard to saline impregnation.

If we fill the tube with water, and place it in a vessel with alcohol, the water becomes charged with alcohol, while the alcohol becomes diluted with water.

There is observed, in these circumstances, that is, when two dissimilar liquids, separated by a membrane, mix together, a phenomenon of a peculiar kind; namely, in most cases a change of volume in both liquids, while the mixture goes on.[‡] The one liquid increases in bulk, and rises; the other diminishes in the same degree, and consequently sinks below its original level.

This phenomenon of mixture through a membrane, accompanied with change of volume, has been distinguished by DUTROCHET, under the name of ENDOSMOSIS and EXOSMOSIS; endosmose is the name given when the volume increases—exosmose, when it diminishes.[§] Very generally, however, we attach to these terms the idea of the unknown cause or group of causes which, in the given case, produce the change of volume; in the same sense as that in which the term capillary action includes the causes which determine the ascent of liquids in narrow tubes.

In all cases, the increase in volume of the one liquid is exactly equal to the decrease in volume of the other, after making allowance for the contraction which the liquids undergo by simple mixture (as in the case of alcohol and water, oil of vitriol and water, &c.,) as well as by evaporation. The unequal concentration, or the unequal density of the two liquids, has a decided influence on the rapidity with which the change of volume takes place; but this cannot be viewed as the cause of that phenomenon. In most cases the denser liquid increases in volume, in others the reverse occurs.

When, for example, the tube contains brine, and the outer vessel pure water, the brine, that is the denser liquid, increases in volume;[‖] but when the tube contains water, and the outer vessel alcohol, the water, that is, the denser liquid, diminishes in volume.

With regard to the mixture of the liquids, the bladder takes a distinct share in the process, inasmuch as it has pores, through which the two liquids are brought in contact.

With reference to the porosity of the bladder, the rapidity of the mixture of the two liquids is directly proportional to the number of particles, which, in a given time, come into contact; it depends also on the surface (the size of the membrane,) and on the specific gravity of the liquids.

The influence of extent of surface on the time required for mixture requires no particular elucidation; that of the unequal specific gravity is rendered evident by the following experiments.[¶]

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[*] Saline solutions pass very rapidly through bladder.

[†] The same is true of bile, milk, urine, serum, &c.

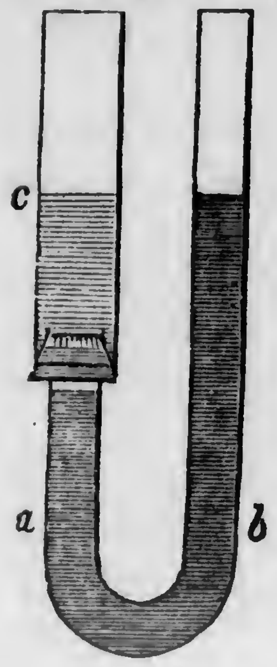
[‡] Change of volume when two dissimilar liquids mix through a bladder.

[§] Endosmosis and Exosmosis.

[‖] The change of volume does not depend alone on the relative density of the liquids.

[¶] Influence of the unequal density of the two liquids, when the lighter liquid is above the membrane.

Fig. 2.



If the bent tube *a b* (Fig. 2,) one end of which is tied over with bladder, and the other open, be filled with brine colored blue,(¹) and if pure water be placed in the tube *c*, there is soon perceived under the bladder a colorless or nearly colorless stratum of liquid, which continues for hours to float in the same place. If the bent tube *a b* be filled with colorless brine, while *c* is filled with pure water colored blue, there is found, after a time, *above* the bladder, a colorless or nearly colorless stratum of liquid.

It appears from this, that an exchange of both liquids goes on through the substance of the bladder; in the first experiment colorless water passes from the tube *c* to the colored brine in the tube *a b;* in the second, colorless brine passes from the tube *a b* to the colored water in the tube *c*.

It is obvious that the brine in the tube *a b*, which is in contact with the bladder, becomes diluted by the addition of water from the tube *c;* but this diluted brine is specifically lighter than the original brine which is below it, and remains therefore floating at its surface.

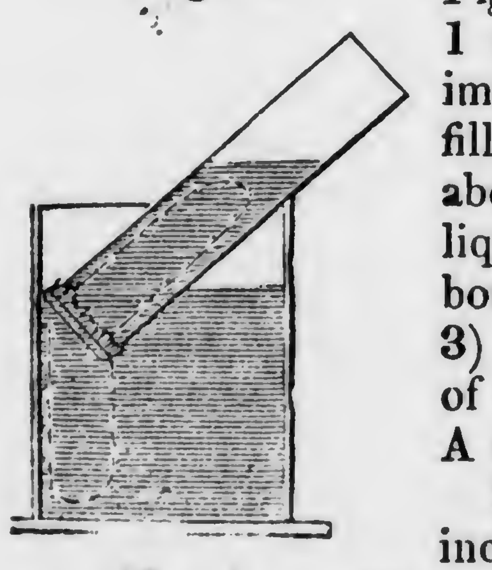
On the other hand, the water in the tube *c*, when mixed with brine from the tube *a b*, becomes heavier than the pure water, and rests, therefore, on the upper surface of the bladder, or that which is turned towards the water.

Hence it follows, that from the moment when these two strata have been formed above and below the bladder, neither concentrated brine nor pure water comes any longer in contact with the bladder.

From the bladder downwards, in the tube *a b* are strata of liquid, containing successively more salt; from the bladder upwards in the tube *c* are strata containing successively more water.

In the beginning of this experiment we observe, that the volume of the water and of the brine changes in both tubes; the liquid in the limb *b* rises from 1 to 2 lines; but as soon as the strata above mentioned have been distinctly formed above and below the bladder, hardly any further rise is perceptible, although the mixture of the liquid proceeds, and the water in *c* becomes constantly more charged with salt, while the brine in *a b* loses salt.

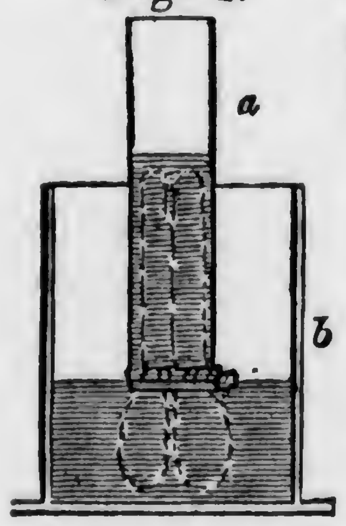
Fig. 3.



If we reverse the positions of the two liquids in the apparatus Fig. 2, or what is simpler, if we close with bladder a tube 1 centimetre ($\frac{4}{10}$ths of an inch) wide, fill it with brine, and immerse the end closed with the bladder in a wider vessel filled with pure water, giving to the tube an inclination of about 45°, we may observe (most distinctly when both liquids contain some fine particles of indigo suspended) in both liquids a continual motion.* We see in the tube (Fig. 3) a current of liquid rising from the bladder in the direction of the arrow, and flowing down again on the opposite side. A similar circulation is observable in the vessel of water.

If the tube *a*, with brine, is about 2 centimetres ($\frac{4}{5}$ths of an inch) wide, and if we support it vertically in the vessel *b* of water, the motion proceeds from the middle, and in both the tube and the vessel we perceive currents in opposite directions. (Fig. 4.)

Fig. 4.



These currents hardly require explanation. To the brine in the tube *a*, pure water passes through the bladder; there is formed above the bladder a mixture containing less salt, and therefore specifically lighter than the brine; this mixture rises, and the denser brine descends to occupy its place.

On the other hand, the pure water receives through the bladder salt, and becomes thereby specifically heavier; while it sinks to the bottom of the vessel, its place is supplied by water containing

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(¹) For this purpose it is best to take a solution of indigo in sulphuric acid, diluted,

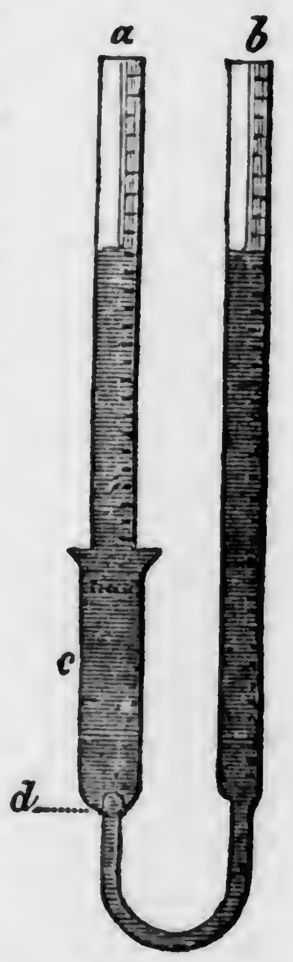
* When the heavier liquid is above the membrane.

less or no salt, and therefore specifically lighter, which again comes in contact with the bladder. As long as the motions just described are perceptible, we observe a constant increase in the volume of the brine in the tube *a* (Fig. 4,) or a diminution in the volume of the pure water in the vessel *b*. When the motions cease, the rise of liquid in the tube is arrested, and when this takes place, the two liquids are found to possess almost exactly the same specific gravity.

When the two strata of liquid on either side of the bladder are little different in composition (as soon comes to pass in the experiment (Fig. 2) where the saline contents of the liquid which fills the pores of the bladder can hardly vary from that of the next stratum,) the mixture of the liquids takes place, but without further change of volume. But when an exchange of the mixtures on the opposite sides of the bladder can occur in consequence of their different specific gravity, and when a continued difference between the strata on opposite sides of the bladder is thus determined, then, so long as (in the case of brine and water, for example) one side of the bladder is in contact with a concentrated, the other with a more diluted solution, the change of volume in the two liquids continues.

As appears from these experiments, the change of volume depends on a difference in the character of the two liquids which are connected through the bladder; and the time during which change of volume occurs is in direct proportion to the time during which this difference in character subsists. The greater the difference in character and composition between the liquids, and the more rapidly this difference is renewed by the exchange between the strata in contact with the opposite sides of the bladder, the more rapidly does the one liquid increase, and the other diminish in volume.

Fig. 5.



The following apparatus is very convenient for measuring the change in volume, caused by the mixture of two liquids separated by a membrane.*

The tubes *a* and *b*, (Fig. 5) are of equal width, and are best taken from the same tube; *a* is closed with bladder, and filled up to a certain point with the liquid whose increase in volume is to be determined. It is then fitted by means of a good cork into the wider tube *c*, which contains distilled water, care being taken to exclude all air bubbles. At *d* lies a small lead drop, which acts as a valve in shutting the opening of the capillary tube connecting *c* with *b*. Pure water is now poured into *b*, and in order to keep in equilibrium the lead drop at *d*, rather more water is added than exactly suffices to bring the liquids to the same level in both tubes.

The liquid in *a* increases in volume, and the height to which it rises may be read off by means of any division into equal parts by measure; the level of the liquid in *b* sinks in an equal ratio. If we keep the liquid in *b*, by the addition of fresh water, at the original level, and if we ascertain the weight of the added water, by pouring it out of a dropping bottle, and determining the loss of weight in the dropping bottle, we learn, at the same time, the weight and the volume of the water which has risen from *c* into *a*. This apparatus admits, of course, of a number of variations and improvements. I have employed it to determine the relation between brine and water, under the circumstances just described. It appeared, among other things, that when the tube *a* is filled with saturated solution of sea salt, the volume of the liquid increased by nearly one half; that is, 200 volumes of such a solution increased to 300. These determinations are, however, not the object of the present investigation, and therefore I pass them over entirely.

The following arrangement, (Fig. 6) will probably be found preferable to the one just described, in many cases. Its construction depends on the observation, that for the phenomenon itself, and for the result of the experiment, it is entirely a

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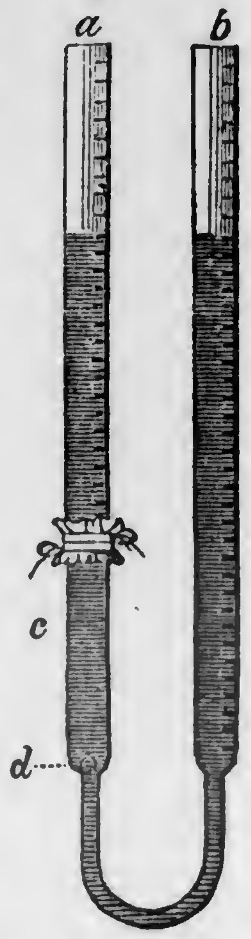
and after adding subacetate of lead as long as sulphoindigotate and sulphate of lead are precipitated, to separate the precipitate by filtration and dry up the filtered liquid in the water bath. A mere trace of the blue residue suffices to color blue large masses of liquid.

* The change in volume may be measured.

Fig. 6.



matter of indifference whether the tube be closed with a single, double, or treble layer of bladder.(1) For experiments on very thin membranes which are permeable to liquids under a very low pressure, the apparatus (Fig. 5) is obviously better adapted. For the explanation of the phenomenon we have to distinguish—

1. The mixture of different liquids.
2. The change in their volume.

As to the mixture of two liquids of dissimilar nature and characters, this always depends on a chemical attraction.* In a mixture of alcohol and water, or of brine and water, there is in every part the same proportion of particles of alcohol and water, or of salt and water. If in the former, the lighter particles of alcohol lying at the bottom of the vessel were not retained, in the place and arrangement which they occupy, by the surrounding particles of water, they would undoubtedly rise towards the surface. In like manner, the particles of salt in the brine are sustained and prevented from sinking by the lighter particles of water which surround them.

Without an attraction, which all the particles of alcohol or of salt must have towards all the particles of water, or all the particles of water must have for all those of salt and alcohol, a uniform mixture cannot even be conceived. If but one particle of alcohol were less powerfully attracted than the surrounding particles, it would rise to the surface; and in like manner, the particles of salt would, in consequence of their greater specific gravity, gradually occupy the bottom of the vessel, were it not that a cause prevents them from rising or falling; and this cause can be nothing but an attractive force, which retains them in the place where they happen to be.

The cause which effects a change in the place or in the properties of the ultimate particles or atoms of dissimilar substances, when these particles are in absolute contact, or at infinitely small distances from each other, as well as the cause which manifests itself as a resistance to such changes of place or properties, we call CHEMICAL ATTRACTION;† and in this sense the mixture of two dissimilar liquids, the simple moistening of a solid body, the penetration and swelling of it by a liquid, are effects in which chemical affinity or attraction has a decided share; and although we are accustomed to limit the notion of affinity to such cases as exhibit a change perceptible to our senses, in the properties of the substances employed, as, for example, when sulphuric acid and lime, or sulphuric acid and mercury combine together, this limitation arises from the imperfect apprehension of the essence of a natural force.

Every where, when two dissimilar bodies come in contact, chemical affinity is manifested. It is a universal property of matter, and by no means belongs to a peculiar class of atoms, or to a peculiar arrangement of these. But chemical combination is not, in all cases, the result of contact.

Combination is only one of the effects of affinity, and occurs when the attraction is stronger than all the obstacles which are opposed to its manifestation.‡ When the forces or causes, which oppose chemical combination, heat, cohesive attraction, electric attraction or whatever they may be called, preponderate, then chemical combination does not take place; and effects of another kind are manifested.

Melted silver in a crucible, surrounded with red hot coals, in a place, therefore, where we should hardly anticipate the presence of free oxygen, absorbs as much

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(1) In these experiments membranes of all kinds may be used. With the thinner membranes, such as the bladder of the calf and the pig, the experiments are more rapidly completed than with the thicker, such as the gall-bladder and urinary bladder of the ox. The peritoneum of the ox and calf is preferable to all others. The tube c is tied with bladder under water.

* Causes of the mixture of dissimilar liquids.
† Chemical affinity is the chief cause of mixture.
‡ Affinity is everywhere active between bodies in contact.

as ten or twelve times its volume of that gas. Metallic platinum exhibits the same property in a far higher degree; for from the atmospheric air, a gaseous mixture in which oxygen forms only the fifth part, that metal (in the form of a black powder) condenses on its surface, at the ordinary temperature, an enormous quantity of oxygen gas (without any nitrogen,) and acquires thereby properties, which it does not otherwise possess.(1) And when oxide of chromium, fragments of porcelain, or asbestus, at high temperatures, effect the combination of two gases, oxygen and hydrogen, or oxygen and sulphurous acid, which gases do not combine at the same temperature, unless when in contact with these solid bodies, it is to the chemical attraction or affinity of these solid bodies that we must ascribe this effect.

The solution of a salt in water is an effect of affinity, and yet no one property, either of the salt or of the solvent, is thereby altered, except only the cohesion of the saline particles.

Sea salt, the crystals of which are usually anhydrous, takes up, at very low temperatures, 38 per cent. of water of crystallization;* not because any new cause acts which increases its affinity for the particles of water (for cold is no cause, but the absence of a cause,) but because the higher temperature acted as an obstacle, opposing their chemical combination. The force of affinity is all the time present and undiminished.

When we add alcohol to the solution of a salt in water, we observe, that now the salt separates from the liquid in the form of crystals, doubtless only because, by the addition of another chemical force, the amount of attraction between the particles of the salt and those of the water has been altered.

The aqueous particles, which were combined with the saline particles, manifest an attraction for the particles of alcohol; and as the latter have no affinity, or only a very feeble affinity, for those of the salt, the attraction of the saline particles for each other is strengthened. This attraction was present in equal force before the addition of the alcohol, but the resistance which opposed their union (the chemical attraction for them of the aqueous particles) was more powerful.† The alcohol was not the cause of the separation. The cause of the separation of the salt from the liquid, its crystallization, is at all times the force of cohesion; and by the alcohol the cause which opposed its manifestation was removed.

The affinity of potash for sulphuric acid is known, and sulphate of potash readily dissolves in water. If we add, to a saturated solution of that salt, an equal volume of aqua potassæ of sp. g. 1.4, there is immediately formed a crystalline precipitate of sulphate of potash, and the sulphuric acid is separated in this form from the water.

In these cases the chemical effect (the separation) depends on the presence of a certain quantity of the liquid which is added (such as aqua potassæ, alcohol, &c.,) but in many other cases there is required only a slight alteration in the quality of the solvent to effect separations of this kind.

When hydrochloric acid is added to a solution of ferrocyanide of potassium, ferrocyanic acid is set free, and remains dissolved in the liquid. If now the vapor of boiling ether be passed through the mixture, there occurs, after a few moments, a complete separation. The whole of the ferrocyanic acid is deposited from the liquid in the form of white or bluish-white crystalline scales, which generally appear in such quantity as to render the whole mass semisolid. In proportion as the vapor of ether is dissolved by the water, the latter fluid loses entirely its solvent power (its affinity) for the ferrocyanic acid. The coagulation of albumen by ether depends on a similar cause.

The capacity of solids to become moistened by liquids, and, in short, all phenomena connected with chemical affinity, are affected, altered, increased, or destroyed by causes quite analogous.

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(1) According to Dœbereiner, platinum black condenses 252 times its volume of oxygen. Its effect in oxidizing alcohol, pyroxilic spirit, &c., is familiar to every chemist.—W. G.

* Crystallization of sea salt.
† Precipitation of salt from its solution by alcohol; of sulphate of potash by caustic potash; of ferocyanic acid by ether; of suspended mud by alum.

After heavy rains, the water of many rivers becomes turbid and opaque from the presence of a fine clay. These suspended particles of clay are so fine as to pass through the finest filters; and their adhesion to the water is so great, that such water does not clear after standing for weeks. The water of the Yellow River, in China, possesses, during the greater part of the year, this character; and from the French missionaries, we know that alum is universally employed in Pekin to clear it. In fact, if a crystal of alum be held in such a water only for a few seconds, we observe the sediment separating in large thick flocculent masses, the water becomes transparent, and hardly a trace of dissolved alum is to be detected by the most delicate re-agents. Chemistry is acquainted with a number of similar means for causing the separation from liquids of suspended precipitates.

In these cases we see, that by an alteration of the quality of the water, produced by what we call mere mixture with a foreign body, its power of combining with others is destroyed or weakened.

It is well known that the force with which, in a solution, the particles of the liquid and those of the dissolved body attract each other, is very unequal in different cases;* and in this point of view the action of many solid bodies on saline solutions is very remarkable; inasmuch as it is thereby demonstrated, that the molecular force, which determines the phenomena of cohesion, and the moistening of solid bodies by liquids appears to be identical with chemical affinity, since chemical compounds can be decomposed by means of it. Professor **Graham** has shown that common charcoal, deprived by acids of all soluble ingredients, completely removes the metallic salts or oxides from solutions of salts of lead, tartar emetic, ammoniated oxide of copper, chloride of silver in ammonia, and oxide of zinc in ammonia; while other solutions, such as that of sea salt, suffer no such change. A bleaching solution of hypochlorite of soda loses entirely its bleaching properties by agitation with charcoal; and iodine can be removed by the same means from its solution in iodide of potassium. Every one is familiar with the action of finely-divided platinum, with that of silver on the deutoxide of hydrogen; as well as with that of charcoal on dissolved organic matters, coloring matters, &c.; and freshly-precipitated sulphuret of lead, sulphuret of copper, and hydrate of alumina, resemble the latter in their action. Many organic substances, such as woody fibre and others, act on dissolved matters, such as salts of alumina or of oxide of tin, just as charcoal does; and we know that the application of mordants in dyeing, and dyeing itself depend on this very property. The adhesion of the solid coloring matter to the cloth which is died with it is the result of a chemical affinity so feeble, that we hardly venture to give the molecular force that name in this case. From a piece of woollen cloth dyed with indigo, the indigo is completely separated, by mere beating, continued for some time, with a wooden hammer, so that the wool is at last left white.

The surface of the solid body exerts, as these facts prove, a very unequal attraction on the molecules, which come in contact with it.

Researches on capillary attraction have shown that, with one and the same liquid, water, for example, the substance of the solid body has no influence on the height to which the liquid rises on it. On slices of box-wood, clay-slate, or glass, the rise of the liquid above the surface of the water is the same exactly as in the case of a plate of brass. (**Hagen.**) In the case of other liquids, the particles of which are entirely homogeneous, the same law may be assumed in theory; but with such liquids as contain foreign bodies in solution, a change in the capillary attraction must be produced by the presence of these bodies, because by them the cohesion of the liquid is altered; and, perhaps, still more because the liquid ceases to be homogeneous, when the attracting wall has a stronger affinity for the particles of the dissolved body than for those of the solvent.

From what has been stated, it appears, that the mixture of two liquids is the result of a chemical attraction; for how otherwise could chemical compounds,

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* Action of solids on dissolved matters.

such as the solution of a salt in water, be decomposed, or a chemical attraction be overcome, by its means?

Two liquids of different chemical properties, which are miscible together, and which, therefore, have a chemical attraction for each other, mix readily at all points where they come in contact.* By motion, shaking, &c., the number of points of contact within a given time is increased, and the formation of a uniform mixture is thus accelerated.

If these liquids be of equal, or still better, of unequal, specific gravity, they may be, with the aid of some precaution, stratified one above the other. This is, in point of time, the most unfavorable case for the mixture, since proportionally small surfaces come in contact. But wherever they do come in contact, it is, after a very short time, impossible to detect any limit between them.

In a cylindrical vessel containing solution of salt, the saline particles at the surface are attracted and sustained by aqueous particles, which exist at the sides of the saline particles and from the surface downwards. From the surface upwards, the attracting aqueous particles are absent.

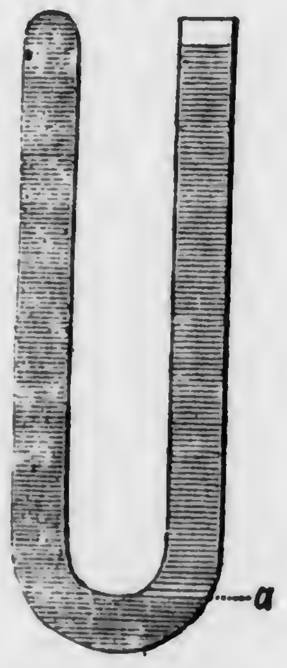
Now it is evident that when the surface is brought in contact with pure water, a new attraction is added to those previously existing, which acts in an opposite direction, namely, the attraction of the aqueous particles floating on the surface for the saline particles, and vice versa (the attraction of the saline particles to the aqueous particles in contact with them.)

At the place where pure water and brine are in contact, there is thus formed a uniform mixture of the two, which upwards is in contact with pure water, downwards with brine.

Among these three strata, of which the upper contains no salt, the lower less water, a new division takes place; the more strongly saline stratum loses salt, the pure water becomes saline, and in this way salt and water are at last uniformly distributed throughout the liquid.

If we fill one limb of the tube (Fig. 7,) as far as *a*, with brine colored blue, and the other limb with water, we find, in the course of a few days, the water colored blue, and the proportion of salt in both limbs equal.† It has been mentioned at p. 15, that, in a tube closed with bladder, filled with diluted solution of salt, and exposed to evaporation, the salt is not deposited in crystals on the outer surface of the bladder till the whole liquid in the tube has reached, in consequence of evaporation the maximum of saturation. The water evaporates from the exterior of the bladder, but no salt is deposited, as long as a liquid exists within which can still dissolve salt; and in this way the heavier saline particles are distributed towards the interior, and upwards through the whole liquid, or, what amounts to the same, the lighter aqueous particles, which can still dissolve salt, are distributed downwards towards the external surface of the bladder.

Fig. 7.



This distribution of salt through water takes place in the same manner as the conversion of bar iron into steel.‡ Rods of malleable iron, as is well known, are kept ignited between strata of charcoal, whereby the surface of the iron in contact with the charcoal takes up carbon, and becomes a carburet of iron. The stratum of iron lying next under this surface, which has the same attraction for carbon, acquires carbon from the superficial stratum immediately in contact with it, and in its turn gives carbon to the stratum below itself. This process, if continued long enough, has no limit till all the strata of particles have acquired an equal proportion of carbon, that is, till they are all saturated with it. A piece of red-hot malleable iron, if kept a few moments in contact with pig iron (a carburet of iron) is found to be already converted into steel at the points of contact. The mixture of liquids depends on the same principle; and we may suppose that their distribution is mutual, because their particles may move in all directions, and that consequently saline particles move towards aqueous particles, as well as aqueous towards saline particles, in virtue of their mutual attraction.

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* Laws of mixture of two liquids.

† Experiment showing the uniform mixture of two liquids.

‡ The distribution of salt through water, resembles the conversion of iron into steel by cementation.

From a solution of sulphate of copper in ammonia, placed in a tall glass cylinder, there is gradually separated, if we pour a stratum of alcohol on the surface, and if we prevent the formation of a coherent crust which impedes the contact of the liquids, the whole of the ammoniated sulphate of copper, while the deep blue solution becomes colorless, because by the distribution of the alcohol through the solution a mixture is formed, in which the salt is insoluble.

The rapidity of mixture of two liquids depends on the degree of their chemical affinity;[*] and the unequal mobility of the particles of one or the other liquid has a favorable or unfavorable influence on the result.

When the one liquid is heavier than the other, and of tough, viscid consistence, a much longer time elapses before the ingredients of the tougher or heavier liquid reach the surface from the bottom of the vessel; and in this case the greater density and the less mobility of the particles are obstacles to the mixture.

On the other hand, if the heavier or more viscid liquid be placed above the lighter, the mixture takes place rapidly; at the points where both liquids are in contact is produced a mixture, which, being heavier, descends, whereby the heavier liquid above is continually brought in contact with new surfaces of liquid.

The very same phenomenon is observed in solution.[†] A fragment of sugar, when covered with water at the bottom of a narrow cylinder, dissolves very slowly, while, if suspended just below the surface, it rapidly disappears. In the former case there is produced round the sugar a thick syrupy viscid solution, which protects the undissolved part of the sugar for a long time from contact with the water; in the latter there is formed at the surface a solution, which descends in striæ, and gradually disappears, while by the change of place thus induced, new portions of water are constantly brought in contact with the undissolved sugar, and are thus enabled to exert their solvent powers.

If skin and membranes consist of a cohering system of very narrow tubes, it is obvious, that when two dissimilar, but miscible liquids are separated by such a tissue, the pores of the tissue will fill with each of the two liquids. In all situations, where the liquids came in contact in the substance of the membrane, a mixture takes place, and this mixture is extended equally towards both sides.

If there be brine on one side of the bladder, and water on the other, there must be formed, in the middle, or at some point of the bladder, a diluted brine, which on the side in contact with the water yields salt to that water, while on the opposite side the strong brine mixes with the diluted brine in the bladder.

The substance of the bladder has no influence on this mixture, because it can produce no change of place on the part of the saline or aqueous particles, for this is the result of the chemical affinity acting between the particles of salt and those of water.

[‡] Now since the rapidity of the mixture of two liquids stands in a direct proportion to the amount of surfaces coming into contact within a given time, and since the liquids, separated by a bladder, can only come in contact through its pores, while the number of points of contact is diminished by the presence of the non-porous parts of the bladder, it follows, that, exclusive of all other effects, the time required for mixture must be lengthened by the interposition of a bladder. In the absence of the bladder, the mixture would take place exactly as when it is present, except in regard to time.

When the heavier brine is under, the water above the bladder, the two liquids mix more slowly than without the bladder.

But since a bladder, inasmuch as a feeble hydrostatical pressure is not propagated through its pores, allows us to place a heavier liquid above a lighter, and to retain it in that position; this circumstance has the effect of promoting mixture, the ultimate cause of which is, not the bladder, but the specific gravity of the liquid.[*] The bladder is a means of enabling the specific gravity to influence mixture. The foregoing remarks appear to me sufficiently to elucidate the share taken by the bladder in the mixture of two dissimilar liquids placed on opposite sides of it.

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[*] Mixture is influenced by chemical affinity, by unequal mobility, and by unequal density in the liquids.

[†] Effect of position on the solution of a solid.

[‡] Rapidity of mixture.

With respect to the change of volume in the two liquids which become mixed through the bladders, we must consider, that the moistening or absorbent power of a solid body, as well as the power of a liquid to moisten other bodies, is the result of a chemical action.[†] Liquids of different properties, or of different chemical characters, are attracted with unequal degrees of force by solid bodies, and exert towards them unequal degrees of attraction, and if we alter even in a system of capillary tubes, filled to a certain height with a liquid, the chemical nature of that liquid, we change thereby the height at which the liquid stands. In an animal tissue saturated with water, the water is prevented from flowing out by the mutual attraction, and by the capillary force, but if the attraction of the organic parietes for water be diminished by the addition of alcohol or of salt to the water, a part of it flows out. To this must be added, that the water absorbed by an animal texture when it enters the capillary tubes, exerts, in virtue of its attraction for the tubes, a certain pressure, by which the vessels are swoln and enlarged. The particles of liquid in these tubes undergo a counter-pressure from the elastic parietes, by which pressure, when the attraction of the liquid particles for the solids is diminished by any new cause, the amount of expelled fluid is increased.

The organic parietes of the tubes, saturated with water, are affected by alcohol just as a salt is when dissolved in water. On the addition of alcohol, or of another liquid, the water separates from the salt, or from the parietes, or the parietes separate from the water.

If the animal tissue possessed as great an attraction for the newly-formed mixture as for the water alone, the volume of the liquid would not change. The mixture would take place, but no water would flow out.

A bladder, saturated with water, when brought in contact with alcohol, shrinks together, a part of the water separates from the animal matter, but there always remains in the bladder a certain amount of water, corresponding to its attraction for the bladder and for the alcohol; just as the solutions of many salts which have a strong attraction for water (such as a metaphosphate and acid phosphate of soda,) and are insoluble in alcohol, are separated by the addition of alcohol into two strata of liquid, the heavier of which is a more concentrated solution of the salt in water, containing a little alcohol, while the other, the lighter, is an aqueous liquid containing much alcohol. The alcohol and the salt divide between them the water of the solution.

When we add, to a mixture of equal parts of acetone and water, a certain quantity of dry fragments of chloride of calcium, the first fragments which are added deliquesce and dissolve entirely in the mixture.[‡] But if we go on adding the salt, a separation soon occurs, two strata of liquid are formed, of which the upper contains acetone and water, the other is an aqueous solution of the chloride with a little acetone. If we add still more of the chloride, water is abstracted from the acetone of the upper stratum, and when a proper quantity has been added, the acetone retains no trace of water.

If we suppose, that of the two originally formed strata of liquid, one of them, namely that which sinks and contains chloride of calcium dissolved, is in contact with a current of dry air, the water of this solution will evaporate, the solution will thus become stronger, and in consequence of its increased concentration will be able to remove a new portion of water from the mixture of acetone and water above it; and this will continue till the acetone is entirely deprived of water.

If in the place of the chloride of calcium we put a bladder, and, in place of the acetone and water, diluted alcohol, we have the finest example of the unequal attraction which the animal tissue exerts on the two ingredients of the mixed liquid.*

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[*] In certain circumstances, the interposition of a membrane accelerates mixture.

[†] Change of volume in liquids which mix through a membrane is the result of chemical affinity modifying capillary attraction.

[‡] Action of chloride of calcium on a mixture of acetone and water.

It is known from the experiments of **Soemmering**, that spirits of a certain strength, inclosed in a bladder, which is opposed to the air, lose by evaporation only water, and that at last anhydrous, or nearly anhydrous (absolute) alcohol is left in the bladder. When strong spirits of wine are used, the bladder remains dry externally; when weaker spirits are employed, it becomes moist, and alcohol evaporates with the water. In virtue of the unequal affinity of the bladder for alcohol and for water, a complete separation is here effected. The water of the mixture is absorbed and evaporates from the outside of the bladder; the alcohol remains in the bladder. As yet, we are acquainted with no substance which can replace the bladder in this operation; and indeed, the affinity of the gelatinous tissues (membranes, &c.) for water must exceed that of all other animal tissues, since a rise of temperature, of a few degrees only, suffices to enable water to dissolve that tissue perfectly into a jelly.

Megnus assumes, "that the particles of every solution, for example, of a salt in water, adhere more strongly to each other than do those of the solvent, for example, of water; consequently, the solution would be less fluid, and pass with greater difficulty through very narrow openings, than water, if we take for granted that the parietes of the openings act alike towards both. It would follow from this, that, the more concentrated a solution, the less easily would it pass through the same openings."†

"Let us now try," pursues **Magnus**, "with the aid of these assumptions, (which, as appears from the experiment Fig. 1, are perfectly accurate and demonstrable for many saline solutions, although there are, according to the researches of **Poiseulle**, a number of exceptions(1)) to explain the phenomena of **Endosmosis**."

"Both the brine and the water will penetrate into the pores of the bladder, and brine will pass from the pores to the water, as well as water to the brine, in virtue of their mutual attraction, till a complete equilibrium is established. Further, since the force which attracts the water to the brine is exactly the same as that which attracts the brine to the water, as much water as brine would pass through the bladder, if both liquids could pass with equal facility through the pores. Since, however, this is not the case, unequal forces are required to urge the two liquids through the pores; or with equal forces, unequal quantities of the two pass through in equal times. There is consequently added more of that which passes most easily, the water to the brine, than of the latter to the water, and the level of both liquids must change, if no other force oppose this change."(2)

According to this theory, brine and water exist in the pores of the bladder in a state of motion, and the chemical affinity, which the particles of the brine have for the particles of the pure water, and conversely, which the particles of water have for those of salt, is considered as the cause of this motion. The unequal velocity, which makes more water flow in a given time to the brine than brine or salt to the pure water, is, according to **Magnus**, determined by the unequal resistance which the substance of the bladder opposes to the passage of the two liquids.

Now, however narrow the tubes may be, in which molecules are set in motion by an external force, it may always be assumed, that that part of the molecules, which is immediately in contact with the wall of the tube, either is not in motion, or possesses only a small velocity, and the velocity of efflux must be a function of the cohesion, and at all events not dependent on the wall of the tube.

If now the efflux of the water on one side of the bladder is produced by the attraction of the saline particles for the water, and the efflux of the brine on the other side is produced by the attraction of the aqueous particles for the saline

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(1) Ann. de Ch. et de Phys. 3rd series, xxi. pp. 84 *et seq.*
(2) Poggendorff's Annales, x. p. 164.

* Effect of evaporation through a bladder in concentrated alcohol
† Views of Magnus on Endosmosis.

particles, it is impossible to explain how water and brine can move in the same tube with unequal velocity in opposite directions; the two liquids being supposed to have a mutual attraction, that is, to be miscible. This attraction must act within the tube just as well without; and we might, therefore, suppose, that when the two liquids have become mixed, the mixture could only move in one direction with a medium velocity.

Assuming that a mixture is formed in the open orifices of the pores or tubes, or in any part of them, it is difficult to see, why saline particles should not pass from one side to the water, or aqueous particles to the saline ones in the bladder, since the mutual attraction must be regarded as equal on both sides. The chemical affinity of the two liquids does not explain the efflux.

If we suppose, that in certain pores only brine, in others only pure water moves, the phenomenon ought not to occur when all the pores are filled with water or with brine, or when the tube is tied with a double, treble, or fourfold, bladder. But the properties of bladder are seen in the finest as well as thickest membranes, and one, two, or three layers make no difference in the ultimate result.(1)

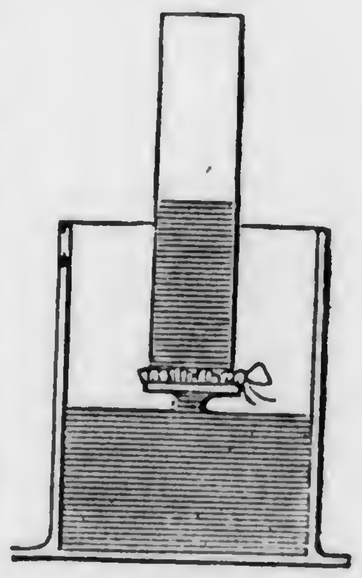
The kind of influence which the nature of the partition, or its attraction for the liquids in contact with it, exerts on the phenomenon, is seen by comparing the action of an animal membrane with that of a thin sheet of caoutchouc.*

In a tube, closed with bladder, which is filled with alcohol, and immersed in pure water, the volume of alcohol is increased; more water passes to the alcohol than alcohol to the water.†

If, without making any other change in the experiment, the tube be closed with a thin sheet of caoutchouc, the volume of the alcohol now diminishes while that of the water increases.

Here, all the circumstances of the mixture of the two liquids have remained the same except the nature of the partition, which makes the difference in the result.

Fig. 8.



When we fill with brine a tube, closed with bladder, (Fig. 8,) and place it in a vessel of water, so that the bladder and water only communicate by a single drop, the liquid in the tube increases in bulk, and rises in the tube, as if the bladder had been immersed in the water; but the drop becomes gradually smaller, till after an hour or two, a complete separation takes place, and the drop tears itself away from the water.(2)

If the cause of the change of volume in this experiment were the unequal resistance which the bladder opposes to the passage of the two liquids with equal attraction (equal force) on both sides, the phenomenon just described would be inexplicable; for a resistance can no doubt impede, but is not capable of producing motion. But we see, that the water in this experiment is raised to a higher level, and moreover, the tearing asunder of the drop can only be the effect of a powerful attraction, residing in the substance of the bladder.

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(1) With respect to the theory, that, when a saline solution is mixed with pure water, if the two liquids are separated by a membrane, particles of salt alone pass through the pores of the bladder to the water, and particles of water alone to the brine, the following experiments may throw some light on the question. For the sake of greater accuracy, the results were determined by weighing. The apparatus, Fig. 3, was used. The tube contained 8·67 grammes of saturated brine, in which were 2·284 grammes of salt and 6·38 of water. After 24 hours it had gained 1·79 grammes in weight, and it now contained only 0·941 grammes of salt. It had therefore lost 1·343 grammes of salt, and gained 3·13 of water. According to the above theory, 1 atom of salt and

[2] If we pour into a tube, ¼ of an inch wide, and closed with bladder, as much mercury as covers the surface of the bladder, then fill it with brine, and place it in pure water, the volume of the liquid in the tube increases exactly as if the mercury were not there.

* The nature of the membrane has an important influence.
† Experiment with bladder, and with caoutchouc.

If the moistening of solid bodies by liquids be the effect of a chemical attraction the force of which is different in dissimilar liquids, it follows that, when a porous body is saturated with a liquid, and brought in contact with a second liquid, which has a stronger attraction for its substance than the first has, then the liquid must be displaced from the pores by the second, even in the absense of hydrostatic pressure, and this, whether the two liquids be miscible or not.[*]

We may suppose that the attraction of the second liquid, of more powerful affinity, which displaces the other, is equal to the pressure of the column of mercury required to force the latter through the porous substance.

If we tie over one end of a cylindrical tube with a very thin membrane, saturated with concentrated brine by steeping 24 hours, and if we dry the outer surface of the membrane carefully with bibulous paper, and now pour a few drops of pure water into the tube so as just to cover the inner surface of the membrane, the outer surface is seen in a few moments to be covered with minute drops of brine; that is, brine flows out of the pores of the bladder.

A thick ox-bladder, saturated with oil, exhibits the same phenomenon in contact with water. The oil is expelled from the pores of the bladder by the water, which occupies its place.

When the bladder is brought in contact with pure water, it takes up a certain quantity of that liquid. If its pores are previously filled with brine, and if we cover one side of it with pure water, the water mixes with the brine in the pores of the bladder; and on the side next the water there is formed a diluted brine, which, being in contact with a stratum of pure water, mixes with it, and in this way the successive strata of water receive, from the bladder outwards, a certain quantity of salt.

In the interior of the bladder, there are formed in like manner, towards the outer surface, mixtures of unequal saline strength. If we suppose the bladder to consist of several strata, all these strata receive, from the surface in contact with the water, a certain quantity of water; the outer stratum, in contact with the air, receives least, and is the most highly charged with salt.

The cause of mixture is the cheminal affinity of the salt for the newly-added particles of water; this affinity is equal on both sides, but the attraction of the substance of the bladder is stronger for the more aqueous or less saline liquid, than for the more concentrated. In consequence of this difference in the attraction of the liquids for the substance of the bladder, a part of the mixture is displaced from the bladder; the less saline liquid takes the place of the more saline; a part of the latter is expelled, and, with it, a part of that water which has been added to the outer stratum by mixture. Brine and water flow out in the direction of least resistance. The efflux towards the side on which the pure water was poured is prevented by the more watery liquid for the substance of the bladder.

If we remove from the outer surface of the bladder the displaced saline liquid (which has been mixed with some water,) and put stronger brine in its place, and if on the opposite side we remove the very diluted solution, replacing it by a still more diluted one, the same process is repeated. There arises a permanent difference, and a state of mixture and efflux continues till the liquids on the opposite surfaces of the bladder have the same, or very nearly the same, composition.

If we suppose, that the two liquids moisten the bladder unequally, it follows,

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[*] One liquid expels another from a membrane.

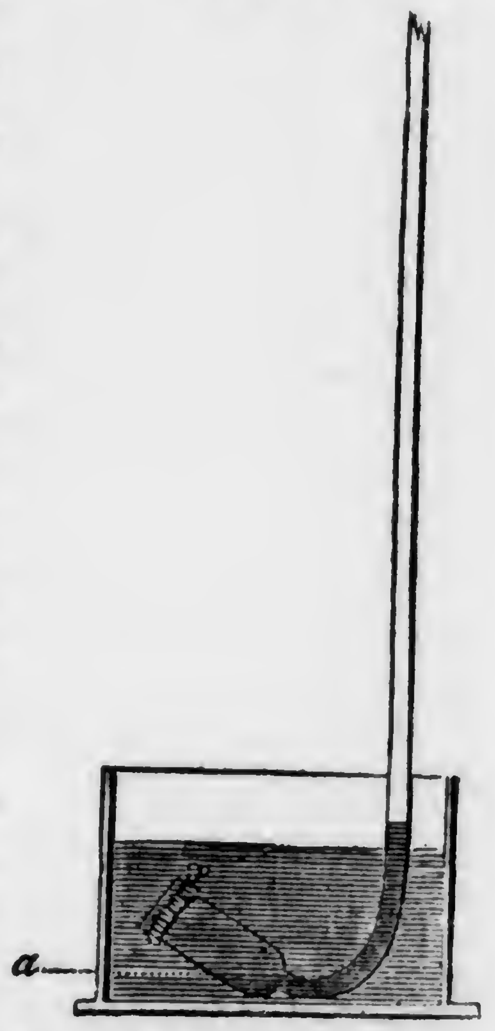
15 atoms of water must have moved past each other; but this is impossible, since 1 atom of salt requires 18 atoms of water for solution, (10 parts of salt to 27 of water.) The weight of the pure water in the outer vessel was 19·26 grammes; consequently, the weight of the brine was to that of the pure water as 1 : 2·22. In another experiment, in which the weight of the brine in the tube was to that of the water outside, as 1 : 7·98; the tube gained 0·822 grammes in weight; the liquid in the tube contained at first 0·947 grammes of salt; and 24 hours after, 0·148 grammes: hence, 1·621 grammes of water had entered, while 0·799 grammes of salt had passed out. For 1 atom of salt, which passed from the tube with brine to the vessel with water, there passed from the latter to the former rather more than 13 atoms of water; (for 58·6 parts, or 1 atom of salt, 118 parts of water.)

that in addition to the chemical attraction which the dissimilar particles of the liquids have for each other, a new cause, namely, the strong attraction of one of them for the substance of the partition, is introduced, which accelerates their motion or passage, and must have this effect, that one of them flows out in larger quantity, in the same time, than the other.

The experiments (Fig. 3) elucidate this process, and show besides, that the exchange of the two liquids on both sides of the bladder is essentially determined by their unequal specific gravities.[*] As long as the difference in their composition (which may here be measured by the specific gravity) is very great, the change of volume (increase of one and decrease of the other) takes place rapidly; but at last, when this difference becomes very small, the liquids mix without further visible change of volume, obviously, because the attraction of the bladder to the mixtures on the opposite sides does not perceptibly differ, although the specific gravities are still somewhat unequal.

In the ultimate result, the action of dissimilar liquids on the substance of animal tissues, in consequence of which their mixture is attended with a change of volume, appears to be equivalent to a mechanical pressure, which is stronger from one side than from the other.[†]

Fig. 9.



[‡] If the tube (Fig. 9,) which is closed with bladder at its wide opening, be filled with brine to the mark *a*, if so much mercury be then poured into the narrow vertical part as by its pressure to cause brine to begin to flow out in fine drops from the pores of the bladder, and if now, after removing so much of the mercury that the efflux is no longer visible, we place the apparatus in a vessel with pure water, colored blue, as in the figure, the mercury does not change its level; and when, after one or two hours, we carefully remove the tube from the water, we find that in the upper part of the wide end of the tube, which contained colorless brine, a dark blue stratum has been formed, which floats on a colorless liquid. After a longer time, the blue color spreads gradually downwards, till at last the brine acquires a uniform blue tint.

It will readily be perceived, that the two liquids here mix, as if no pressure had been applied to the brine, for a mechanical pressure exerts no influence on the mixture; but, in consequence of the pressure, the mixture takes place without change of volume. The mechanical pressure which the water, in virtue of its stronger affinity for the bladder, exerts on the brine in the pores of the bladder, is held in equilibrium by the column of mercury, and the result is that exactly as much brine flows out as water flows in.

[§] Let us suppose the column of mercury to be removed, and the rise of the brine in the narrow tube is explained at once. If we close a short tube, filled with alcohol or brine, with bladder at both ends (an arrangement which may represent a cell,) and suspend it in a vessel of pure water, both surfaces of the bladder become convex outwards; they swell, but without bursting. As soon as the pressure, gradually increasing by the influx of water into the interior of the tube, is sufficient to keep in equilibrium the affinity of the water for the bladder, and consequently its further influx, the exchange goes on, for the future, without change of volume.

Most porous bodies exhibit the phenomena described in the preceding pages, if their pores are so minute that a feeble hydrostatic pressure is not propagated through them.* These phenomena may be produced with clay cells (1) (such as are used for galvanic apparatus;) with the lining membrane of the pods of peas and beans; with the fine inner bark of trees; with the skin of grapes, of potatoes, of apples; with the inner membrane of the capsules of bladder senna, &c.; but animal tissues surpass all others in efficacy. Besides their unequal affinity, they have an unequal absorbent power for dissimilar liquids, by which their action in causing change of volume during mixture is strengthened.

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[*] Mixture is essentially determined by the unequal density of the liquids.

[†] The action of two liquids on animal tissues equivalent to a mechanical pressure, unequal on opposite sides.

[‡] Experiment to show that an external pressure prevents change of volume.

[§] Additional experiment.

When a tube, closed with bladder, and filled with water, is immersed in alcohol or brine, there is produced at all points, where the brine or the alcohol comes in contact with bladder saturated with water, a change in the properties of the bladder.† When, in the open pores, the alcohol or brine mixes with the water already there, the absorbent power of the bladder for the water is diminished; a smaller volume of the mixture is retained than of pure water; that is to say, water flows out in the direction of the alcohol or brine. This efflux is accompanied by a change in the volume of the substance of the bladder, for that side of it which is towards the alcohol or the brine contracts or shrinks.

The opposite surfaces of an animal membrane, in contact with dissimilar liquids, for which they have unequal absorbent power, are in an unequal state of contraction. This condition is permanent, as long as the liquids do not change in their properties; but it ceases, in consequence of mixture, and is again restored, when, by means of the change of place in both the liquids which are in contact with the opposite surfaces of the bladder, the original or any other permanent inequality or difference of properties is produced.

In all cases where a permanent change in the volume of two liquids, separated by a membrane, is observed during their mixture, it is always accompanied by a permanent difference in the nature or properties of the two liquids; and from this it follows, that the molecules of the animal membrane must be, during the mixture, in an alternate state of contraction and swelling, or dilatation; that is, *in a continual motion.*‡

From what has been stated, it appears that the change of volume of two miscible liquids, separated by a membrane, is determined by the unequal capacity of being moistened, or the unequal attraction of the membrane for these liquids. The unequal absorbent power of the membrane for these liquids depends on the dissimilar nature of the liquids or of the substances dissolved in them. An unequal proportion

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(1) I consider it of sufficient importance to state here that porous clay also takes up unequal volumes of brine and water. In special experiments made on this subject, cells of clay (moderately ignited porcelain biscuit) were laid for 24 hours in pure water, then carefully dried externally with bibulous paper, and the increase in weight, that is, the weight of the absorbed water, carefully determined.§ The clay was then carefully dried, laid for 24 hours in brine, and the weight of the absorbed brine determined in like manner. In a second series of experiments, the clay cells were steeped in water and brine, and placed in the receiver of the air-pump, under a pressure of 8 lines of mercury (⅔ of an inch) for 24 hours.

Under the ordinary pressure, and in air the cells absorbed—

		Weight.		Volume.	
		Water.	Brine.	Water.	Brine
100 parts of clay cell........	I.—	15·4	14·6	15·4	12·2
	II.—	11·8	11·6	11·8	9·7

In vacuo the cells of clay absorbed—

		Weight.		Volume.	
		Water.	Brine.	Water.	Brine.
100 parts of clay cell absorbed	I.—	16·5	16·8	16·5	14·0
	II.—	13·8	13·8	13·8	11·5

* Porous bodies in general exhibit similar phenomena.

† Bladder shrinks in contact with brine or alcohol.

‡ Change of volume in two liquids, separated by membrane, is accompanied by continual motion in the particles of the membrane; and depends on the unequal attraction of the membrane for the liquids.

§ Amount of liquids absorbed by porous baked clay.

of the same dissolved matters (unequal concentration,) acts in many cases, just as if the liquids contained dissimilar substances.

Although the experiments hitherto instituted, and the results obtained by **Fischer** (who first observed these phenomena,) **Mangus**, **Dutrochet**, and others, admit of no comparison, since the apparatus used by them showed only relative change of volume, yet a knowledge of some of these results is, nevertheless, of importance.

When the two liquids are, diluted sulphuric acid (of sp. g. 1·093) and water, the acid, at 50° F., increases in volume; but if the acid have the specific gravity 1·054, the volume of the water increases,*

Diluted tartaric acid (11 parts of the crystalized acid and 89 of water) and water mix through a bladder without change of volume; with more than 11 per cent. of acid, the volume of the acid increases; with less that of the water.

Solutions of animal gelatine, gum, sugar, and albumen increase in volume when separated by a bladder from water; and the increase of volume in these different solutions, although of the same specific gravity, is very different indeed. When the specific gravity is 1·07, the increase in volume of the solution of gelatine amounts to 3, that of solution of gum to 5, of sugar 11, of albumen 12. When a solution of sugar (1 part of sugar to 16 of water) is separated by a bladder from water, it increases in volume; but if we add 1 part of oxalic acid to the sugar, the water, on the contrary, increases in volume. If the amount of sugar in the solution be doubled, the liquids mix without change of volume. A solution of sugar, separated by bladder from one of oxalic acid, rises, in the same time, 3 times higher than when separated from water. (**Dutrochet.**)

From these experiments we obtain, as a universal result (which, however, requires confirmation,) that an animal membrane possesses a less power of absorption for solution of albumen than for all other organic substances:† and that a small amount of mineral or organic acids increases the power transudation of water as well as of the solutions of many organic substances.‡(1)

The rapidity of mixture of two liquids, separated by a membane, depends on the thicknes of the membrane, and stands in direct proportion to the velocity with which the mixture formed in the pores and on both surfaces of the bladder changes its place, and the original difference in the quality of the two liquids is renewed.§

‖ If we suppose a tube, formed of a membrane (an intestine, for example,) and filled with water, and if we assume that a current of saline solution flows round this tube, in consequenee of a mechanical force, the increase of volume of the brine (the passage into it of a certain amount of water) will be effected in a far shorter time than if the brine were not in motion.

The velocity of transference will diminish with the amount of difference in properties between the two liquids (the different amount or per centage of salt;)¶ it will be greatest at first, and diminish as the dilution of the brine increases, in proportion, that is to say, as water is transferred from the contents of the tube to the liquid without.

The greatest effect, therefore, must occur and be permanent, when the water transferred to the brine is continually again removed from it, that is, when the concentration of the brine is kept uniform.** To this end, if we suppose the membrane to be difficultly permeable for one liquid, while the other is easily taken up into its pores, and if we reflect, that this second liquid, on entering into the pores of the bladder, in virtue of the attraction of their walls for it, acquires a certain velocity which permits it to pass beyond the extremitiss of the canal or the pores, so as to entirely fill the pores, and to come in direct contact with the liquid on the outside of the pores, it follows, that, when this second liquid moves past the poses with a certain velocity, the absorbed liquid must follow it during the mixture, and there must take place a rapid transference of the second liquid to the first, a true suction as if by a pump.

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(1)In order not to be misled in such experiments, we must avoid the employment of all those liquids which alter the membrane in its chemical properties. Such are, for example, acids of a certain concentration, nitrate of silver, salts of lead, chloride of gold, chloride of tin, chromic acid, bichromate of potash, taunic acid, &c. Even in water, the properties of membranes generally undergo a change after some days, they then propagate a far weaker hydrostatic pressure through their pores, and are no longer fit for such experiments.

* Examples of change of volume; in acids, and neutral organic substances, according to **Dutrochet**

† Membranes have a feeble power of absorbing solution of albumen.

‡ Effect of adding acids.

§ Causes which influence rapidity of mixture.

‖ Motion of one of the liquids.

¶ Difference in properties of the two liquids.

** Effect of the continual removal of the transferred liquid analagous to suction.

The animal body is an example of an apparatus of this kind in the most perfect form.[*] The blood vessels contain a liquid, for which their walls are, in the normal state, far less permeable than for all the other fluids of the body. The blood moves in them with a certain velocity, and is kept at all times in a nearly uniform state of concentration by a special apparatus, namely, the urinary organs.

The whole intestinal canal is surrounded with this system of blood vessels, and all the animal fluids, in so far as they are capable of being taken up by the parietes of the intestinal canal, and of the blood vessels situated around it, are rapidly mixed with the blood.[†] The volume of the blood increases, if no compensation is effected by means of the kidneys: and the intestine is emptied of the liquids contained in it. The intestinal glands, through which this transference is effected, and each of which represents a similar apparatus of suction, contain, within them, two systems of canals,—blood vessels and lacteals; the blood vessels are placed next to the external absorbent surface, the lacteals chiefly occupy the central part of the gland. The liquids circulating in these two systems have very unequal velocities, and as the blood moves much faster in the blood vessels, we perceive how it happens, that the fluids of the intestine are chiefly (in quantity and in velocity) taken up into the circulation.

The difference in the absorbent power of the parietes of the intestinal canal for liquids which contain unequal amounts of dissolved matters, is easily observed in the effects produced on the organism by water and saline solutions.[‡]

If we take while fasting, every ten minutes, a glass of ordinary spring water the saline contents of which are much less than those of the blood, there occurs, after the second glass (each glass containing 4 ounces,) an evacuation of colored urine, the weight of which is very nearly equal to that of the first glass; and after taking, in this way, 20 such glasses of water, we have had 19 evacuations of urine, the last of which is colorless, and contains hardly more saline matter than the spring water.

If we make the same experiment with a water, containing as much saline matter as the blood ($\frac{3}{4}$ to 1 per cent. of sea salt,) there is no unusual discharge of urine, and it is difficult to drink more than three glasses of such water. A sense of repletion, pressure, and weight of the stomach point out, that water as strongly charged with saline matter as the blood requires a longer time for its absorption into the blood vessels.

Finally, if we drink a solution containing rather more salt than the blood, a more or less decided catharsis ensues.[§]

The action of solution of salt is of three kinds, according to the proportion of salt. Spring water is taken up into the blood vessels with great rapidity; while these vessels exhibit a very small power of absorption for water containing the same proportion of salt as the blood does; and a still more strongly saline solution passes out of the body—not through the kidneys, but through the intestinal canal.

Saline solutions and water, given in the form of enemata, exhibit similar phenomena in the rectum.[‖] Pure water is very rapidly absorbed, and excreted

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[*] This occurs in the animal body.
[†] Absorption of the liquids of the intestines into the blood.
[‡] Effects produced by drinking water and saline solutions.
[§] Solution containing more salt than the blood.
[‖] Enemata of water and saline solutions.

through the urinary passages. If we add to the water colored or odorous matters, these appear, more or less changed in the urine. When a small quantity of ferrocyanide of potassium is added, its presence in the urine is very soon detected by chloride of iron, which forms with it Prussian blue. Of concentrated solutions far less is absorbed in the same time, than of diluted; in most cases they mix with solid matters collected in the rectum, and are expelled in the form of a watery dejection.

All salts do not act alike in this respect. In equal doses, the purgative action of Glauber salt and Epsom salt is far stronger than that of sea salt; and their power of being absorbed by animal membranes appears to be in the inverse ratio of this effect. It is hardly necessary, particularly to point out that an explanation of the action of purgatives in general cannot be included in the above-described action of saline solutions on the organism. The example which has been given is intended to illustrate a physical property common to a large number of salts, and apparently of the nature of the acid or base of the salt; for chloride of calcium, chloride of magnesium, bitartrate of potash, tartrate of potash and soda, phosphate of soda, and certain doses of tartar emetic, show the same action as sea salt, Glauber salt, and Epsom salt, although the bases and acids in these different salts are not the same.

Solutions of cane sugar, grape sugar, sugar of milk, and gum, exhibit, when separated from water by an animal membrane, phenomena similar to those exhibited by the above-named solutions of mineral salts, without causing in the living body a purgative action, when of equal concentration. The cause of this difference may be that the mineral salts, in their passage through the intestinal canal, and through the blood, are not essentially altered in their composition, while these organic substances, in contact with the parietes of the stomach, and under the influence of the gastric juice, suffer a very rapid change, by which the action which they have out of the body is arrested.

Since the chemical nature and the mechanical character of mebranes and skins exert the greatest influence on the distribution of the fluids in the animal body, the relations of each membrane presenting any peculiarity of structure, or of the different glands and systems of vessels, deserve to be investigated by careful experiment;[*] and it might very likely be found that in the secretion of the milk, the bile, the urine, the sweat, &c., the membranes and cell-walls play a far more important part than we are inclined to ascribe to them; that besides their physical properties, they possess certain chemical properties, by which they are enabled to produce decompositions and combinations, true analyses; and if this were ascertained, the influence of chemical agents, of remedies, and of poisons on those properties, would be at once explained.

The phonomena described in the preceding pages are observed, not in the gelatinous tissues alone, but also, apparently, in many other structures of the animal body, which cannot be reckoned as belonging to that class.[†]

If we tie moist paper over the open end of a cylindrical tube, and, after pouring in above the paper white of egg to the height of a few lines, place that end of the tube in boiling water, the albumen is coagulated, and when the paper is removed, we have a tube closed with an accurately fitting plug of coagulated albumen, which allows neither water nor brine to run through.[‡] If the tube be now filled to one-half with brine, and immersed in pure water, as in Fig. 4, the brine is seen gradually to rise; and in three or four days it increases by from $\frac{1}{4}$ to $\frac{1}{2}$ of its volume, exactly as if the tube had been closed with a very thick membrane

Influence of the cutaneous evaporation on the motion of the fluids of the animal body.

When a tube about 30 inches long, bent in the form of a knee, and widened at one end, is tied over at that end with a piece of moist ox-bladder, the bladder now thoroughly dried, and the tube filled with mercury and inverted, so that the open, narrow end stands in a cup of mercury, the mercury in the tube falls to about 27 inches (Hessian,) and remains, if the bladder have no flow, at that height, rising and falling as the mercury does in a barometer.

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[*] Influence of membranes on secretions.
[†] These phenomena not confined to the gelatinous tissues.
[‡] Coagulated albumen acts like a thick membrane.

No air passes through the dry bladder into the Torricellian vacuum thus produced. When, by proper manipulation, we have allowed to pass out as much as can be removed of the air still contained in the tube, we have, in this arrangement, a barometer, containing no more air than would be found in one made with a similar tube hermetically sealed at the wide end, provided the mercury in the latter had not been boiled in the tube to expel the last traces of air. By the desiccation of the bladder, its pores, which allowed a passage to water, brine, oil, or even mercury, have obviously been closed by the adhesion of the successive layers of membrane, which perhaps cross each other, so that the bladder is not more permeable for the particles of air than a slice of horn of the same thickness.

Fig. 10.

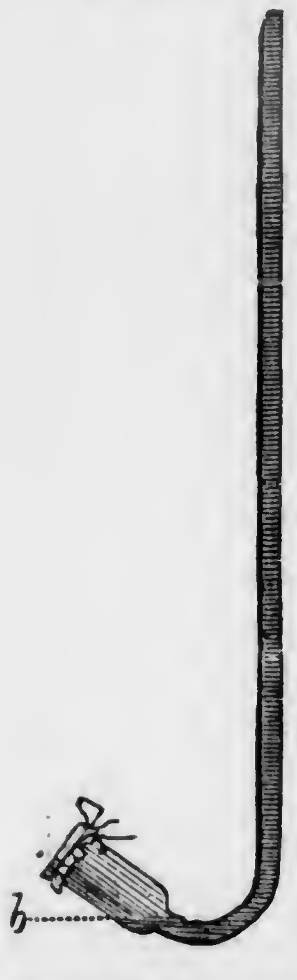
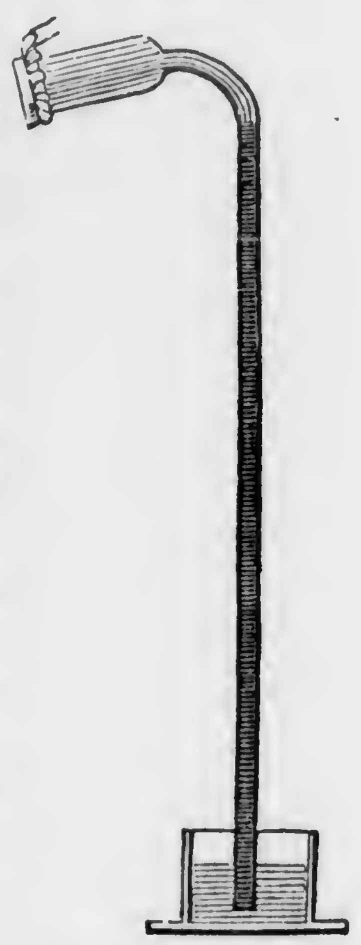


Fig. 11.



If we introduce water into the tube in the position, Fig. 10, to the line marked *b*, and, after filling the narrow part of the tube with mercury, invert it in a vessel of mercury, Fig. 11, we observe a number of minute bubbles of air passing through the moist bladder into the tube. The mercury falls to a certain point, which is higher or lower according to the thickness of the bladder; it stands at a lower level with a thin membrane than with a thick one. When a single layer of ox-bladder is used, it falls to 12 inches (above the level of the mercury in the vessel;) with a double layer it stands at from 22 to 24 inches.

If we take care to allow the water standing above the mercury to enter the wide part of the tube, so that the bladder is kept at all times covered with water, the mercury remains stationary at the same level. If, for example, it stood at 12 inches, it remains there, although the quantity of water is constantly diminishing by evaporation from the bladder; and it maintains its level, even after all the water has disappeared.

The height of the mercury in the narrow tube is an exact measure of the pressure acting on the surface of the bladder. The pressure in the inside of the tube is less than the existing pressure of the atmosphere outside by the height of that column of mercury.

This difference of level between the mercury in the vessel and that in the tube is the limit of the pressure, under which air passes into the water through the pores of the bladder; or under which the molecules of water in the pores are displaced by the molecules of air.

If we fill the tube entirely with water, and place the narrow end in mercury, while the wide end, closed with bladder, is exposed to the air, the mercury rises in the narrow limb, and at last reaches a point, identical with that to which it fell in the preceding experiment. For each specimen of bladder, according to its thickness, the level to which the mercury reaches is of course different.

When the diameter of the wide part of the tube, which is closed with bladder, is 12 millimetres, and that of the narrow tube 1 millimetre, the mercury rises, with ox-bladder, according to the temperature and the hygrometric condition of the air, to from 22 to 65 millimetres in one hour.

The cause of the rise of the mercury in this experiment hardly requires a special explanation.

The bladder is penetrated with water, covered on one side with water, and on the other in contact with a space (the air) not saturated with aqueous vapour The water contained in the pores of the side of the bladder turned towards the air

evaporates; the space which it had occupied in the pores is filled with successive portions of water from within, in virtue of the attraction of the substance of the pores for water. The volume of the water in the tube diminishes, and thus a vacuum arises, in which the mercury is forced to rise by the atmospheric pressure. The space formerly occupied by the water which has evaporated is now filled with mercury.

When the mercury has reached a permanent level, the external pressure, which acts on the water in the pores of the bladder (and which tends to displace the particles of water) is obviously equal, before air enters, to the attraction which the substance of the bladder has for the particles of water, and these last to each other. Were the attraction less, air would enter, and the particles of water could not maintain their position.

The rise of the mercury, or its motion towards the surface of the bladder, that is, towards the point where evaporation is going on, is the result of a difference of atmospheric pressure, determined by the evaporation of the water, or of the liquid which penetrates through the bladder, and by the absorbent power of the bladder for that liquid.

One chief condition of the efficiency of a bladder, in regard to the rise of a coulmn of liquid, is, that it is kept constantly in contact with the liquid, for without this contact the absorbent power cannot manifest itself.

By the evaporation a continual efflux of water, in the form of vapour, towards the side on which the air lies, is produced; and by the capillary action of the bladder on the other side, water is absorbed and retained with a force which counterpoises 12 or more inches of mercury, according to the thickness of the bladder.

Now, since the rise of the mercury is an effect of the atmospheric pressure, it is plain, that the height to which the mercury rises, must depend to a certain degree on the state of the barometer.[*]

In a tube filled with water, and closed with bladder, the absorbent force of which is equal to the pressure of a column of 12 inches of mercury, the mercury rises by evaporation to the height of 12 inches, as long as a column of 12 inches of mercury can be sustained by the external atmospheric pressure. If this external pressure fall below that limit, the mercury in the evaporation tube falls to the same extent, and if there be water above the mercury, this water separates from the bladder.

This property of bladder, therefore, would appear unaltered at an elevation at which the barometer should stand at 12 inches; at a still greater elevation, on the contrary, the liquid would separate from the bladder.

The external pressure has no influence on the amount of the water evaporating in the pores of the bladder; that amount depends on the hygrometric state of the surrounding air, and on the temperature.[†] In a rarified air, (provided it can take up moisture,) evaporation goes on more rapidly than in a denser air; and hence it is clear, that at certain elevations, the effect of the bladder on the level of the liquid is more quickly produced than at the level of the sea. The amount of water which evaporates is directly proportional to the surrounding space, and to the temperature and corresponding tension of the liquid.

When the tube, Fig. 10, is filled with water to *b*, then entirely filled with mercury and inverted in mercury, the mercury, as we have seen, assumes a fixed level. If we now keep the upper or wide end of the tube, which is closed with bladder, immersed in a vessel of water, Fig. 12, we shall find, after a short time, that the mercury sinks in the narrow tube. If its level has been 12 inches above that of the mercury in the vessel, it sinks when the bladder is put into water, 3 or 4 inches for example, and remains stationary at 8 or 9 inches, without sinking further for the next 12 hours.

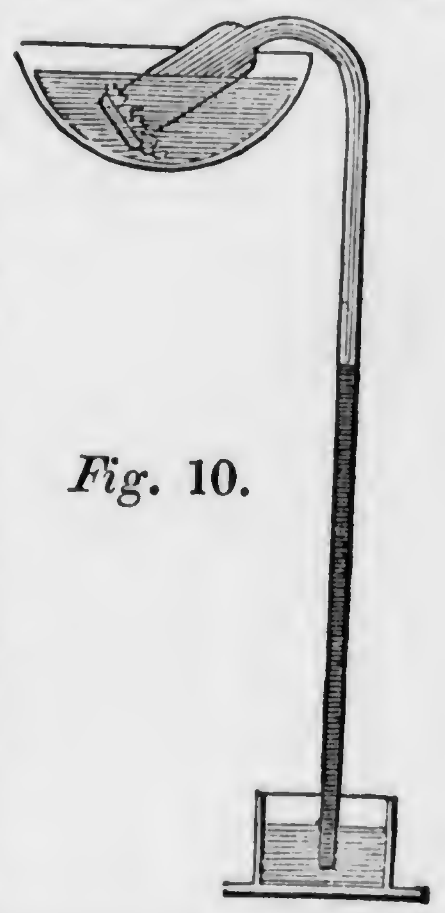


Fig. 10.

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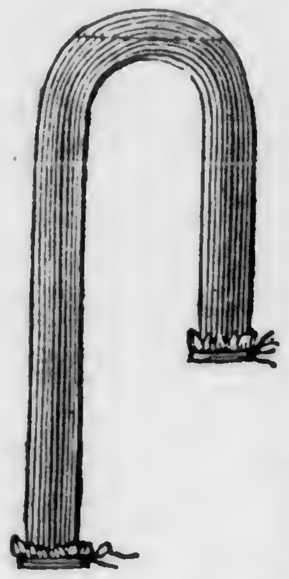
[*] Influence of the state of the barometer

[†] The pressure of the air does not affect the amount of evaporation.

The sinking of the mercury is caused by water being forced through the bladder into the tube, in virtue of the existence of an external pressure greater than the pressure on the inside of the tube.

To displace the aqueous particles in the pores of the bladder by other aqueous particles, requires obviously a much smaller pressure than is necessary to displace them by particles of air.* In the one case, where both surfaces of the bladder are in contact with the liquid, the attractive force (that of the bladder for the water and of the water for the bladder) is equal on both sides; but not so in the other case, where one side of the bladder is in contact with air. If the bladder had the same absorbent power for the particles of air as for those of water, the particles of air and water would pass through the bladder under the same pressure; the experiment shows, that the absorbent power and permeability of the bladder for air is far less than for water. Hence, it comes to pass, that when, with a given portion of bladder, in the apparatus Fig. 11, mercury is raised by evaporation to a heighth of 12 inches, less than 12 inches of mercury are required, in the apparatus, Fig. 1, to cause water to pass through the bladder.

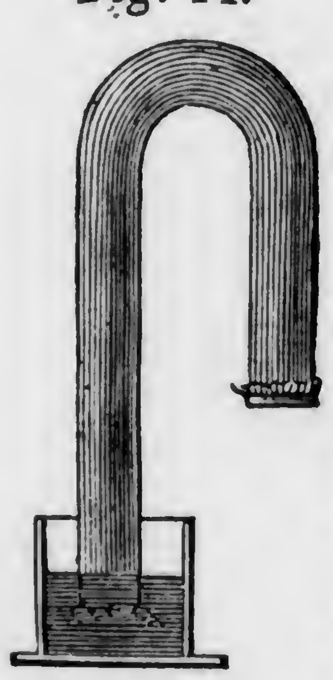
Fig. 13.



† When the tube, (Fig. 13,) is filled with water, closed with bladder at both ends, and exposed to evaporation, the bladders in a short time become concave, that is, they are pressed inwards. As the evaporation of the water through the moist surfaces of the bladder proceeds, there is formed in the upper part of the tube a vacuum, which is filled with aqueous vapor, and which continues to increase. The place of the water which evaporates is, as in the experiments previously described, gradually occupied by air, which enters the tube through the bladder.

It is evident, that when air enters the tube, (Fig. 13,) the pressure on the surface of the bladder is equal to the absorbent force of that bladder for the water. In the apparatus, Fig. 11, with the same bladder, the mercury might have been raised, in consequence of the evaporation, to a height of 4, 6, 12, or more inches, according to the thickness of the membrane.

Fig. 14.



When the longer limb of the bent tube, after it has been filled with water, and closed at both ends with bladder, is placed in a vessel containing brine, and exposed to evaporate in the air, as in Fig. 14, it is plain, that when the atmospheric pressure, increasing in consequence of the evaporation of the water on both the surfaces of the bladder, reaches the point at which the brine flows through the pores of the bladder, then the place of the water which evaporates is occupied by brine.

In fact, when the brine is colored blue, we observe, after a few hours, that a blue stratum forms within the tube, which constantly increases, till at last the vessel of brine is emptied, and the tube is entirely filled with brine.

If the longer limb be immersed in bile instead of brine, the tube fills with bile, and if we employ, for closing one end, a membrane rather thinner than we use for the other, from which the evaporation takes place, and then place the end with the thinner membrane in oil (oil of marrow,) the tube gradually fills with oil.

In all these cases, no air enters the tube, which continues full of liquid, as it was at first.

‡ If we connect the evaporation tube by collars of caoutchouc with short bits of tube (Fig. 15,) full of water, and tied with bladder at both ends; and if we immerse the last bit of tube in brine, urine, oil, &c., all these cells, and at last the evaporation tube itself, become gradually filled with brine, urine, oil, &c.

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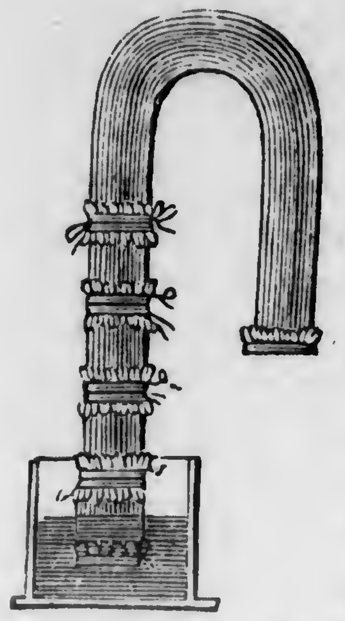
[*] Water passes through moist bladder more easily than air does.

[†] Experiments with a tube closed at both ends with bladder: with one end in brine, the tube being filled with water, with one end in bile, and in oil.

[‡] Effect of a series of short tubes, closed at both ends with bladder.

Fig. 15.



* The most general expression for these experiments and results is this;—that all liquids which are in connection with a membrane from the surface of which evaporation can take place, must acquire motion towards that membrane.

The amonnt of this motion is directly proportional to the rapidity of evaporation, and consequently to the temperature and hygrometric state of the atmosphere.

That the skin of animals, and the cutaneous transpiration, as well as the evaporation from the internal surface of the lungs, exert an important influence on the vital processes, and thereby on the state of health, has been admitted by physicians ever since medicine has existed; but no one has hitherto ascertained precisely in what way this happens.†

From what has gone before, it can hardly be doubted, that one of the most important functions of the skin consists in the share which it takes in the motion and distribution of the fluids of the body.‡

The surface of the body of a number of animals consists of a covering or skin permeable for liquids, from which, when, as in the case of the lung, it is in contact with the atmosphere, an evaporation of water, according to the hygrometric state and temperature of the air, constantly goes on.§

If we now keep in mind, that every part of the body has to sustain the pressure of the atmosphere, and that the gaseous fluids and liquids contained in the body oppose to this pressure a perfectly equal resistance, it is clear that, by the evaporation of the skin and lungs, and in consequence of the absorbent power of the skin for the liquid in contact with it, a difference in the pressure below the surface of the evaporating skin occurs. The external pressure increases, and in an equal degree the pressure from within towards the skin. If now the structure of the cutaneous surface does not permit a diminution of its volume, a compression (in consequence of the loss of liquid by evaporation,) it is obvious that an equalization of this difference in pressure can only take place from within outwards; first from within, and especially from those parts which are in closest contact with the atmosphere, and which offer the least resistance to the action of the external pressure.‖

Hence it follows, that the fluids of the body, in consequence of the cutaneous and pulmonary transpiration, acquire a motion towards the skin and lungs, which must be accelerated by the circulation of the blood.

By this evaporation, the laws of the mixture of dissimilar liquids, separated by a membrane, must be essentially modified.¶ The passage of the food dissolved in the digestive canal, and of the lymph into the blood vessels, the expulsion of the nutritive fluid out of the minuter blood vessels, the uniform distribution of these fluids in the body, the absorbent power of the membranes and skins, which, under the actual pressure are permeable for the liquids in contact with them, are under the influence of the difference in the atmospherical pressure, which is caused by the evaporation of the fluids of the skin and lungs.

The juices and fluids of the body distribute themselves, according to the thickness of the walls of the vessels, and their permeability for these fluids, uniformly through the whole body; and the influence which a residence in dry or in moist air, at great elevations or at the level of the sea, may exert on the health, in so far as the evaporation may thus be accelerated or retarded, requires no special explanation; while on the other hand the suppression of the cutaneous transpiration must be followed by a disturbance of this motion, in consequence of which the normal process is changed where this occurs.

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[*] Liquids move towards the membrane from which evaporation takes place.

[†] Influence of the skin and cutaneous transpiration on health.

[‡] The cutaneous evaporation has an important share in causing the motion of the animal fluids.

[§] Evaporation is constantly going on from the skin and lungs.

[‖] This evaporation must produce unequal pressure, by which the fluids acquire a motion towards the skin and lungs.

[¶] The change of pressure influences the mixture of the fluids.

The pressure, which, in consequence of the evaporation, urges the fluids within the body to move towards the skin, is, as may readily be understood, equal to the difference of pressure acting on the surface of the skin.*

From the experiment, Fig. 13, it is plain, that when one of the two surfaces of bladder at the ends of the tube Fig. 12, is exposed to atmospheric evaporation, while the other end is moistened with water, brine, or oil, these liquids are rapidly absorbed by the membrane, that is, are forced in by the external atmospheric pressure, and it is not less obvious, that the same thing takes place with the liquid with which one of the two evaporating surfaces has been moistened in the middle only; while the evaporation continues around the moistened spot.

If, therefore, we moisten with a liquid the surface of the evaporating skin at any point, the liquid is forced inwards by the external pressure.†

Let us suppose any part of the skin to be rubbed with fat, the transpiration ceases at that part.‡ If now the skin around the part is in its normal activity, if, therefore, in the surrounding parts liquid is constantly passing off by evaporation, the fat must be urged, by the unequal pressure thus arising, towards these parts, or it is absorbed, just as water, in the apparatus, Fig. 12, is absorbed, when in consequence of evaporation a difference between the internal and external pressure has arisen. If the whole skin were covered with fat, the absorption would be effected by the pulmonary evaporation.

The blistering of the skin, and the sun-burning, to which men are exposed at great elevations, arise from the extraordinary dryness of the air, the increased evaporation, and the pressure by which the fluids filling the vessels are forced towards the surface.

Several causes contribute jointly to the appearance of the sweat, to the efflux of fluid, from the pores of the skin. One of these obviously depends on the velocity, which the fluid set in motion by evaporation or by a mechanical cause, acquires from the accelerated motion of the blood. In consequence of this velocity, the fluid moves out beyond the limits of the absorbing membrane or skin.

The changes of the vital process, caused by the unequal distribution of fluid in the body in consequence of evaporation, are best seen in animals which live in water, in whom, therefore, the above explained cause of motion in the normal state does not act. When a fish is held immersed in water, so that the head is out of the water, while the rest of the body is covered, it dies in a few minutes.§ It dies exactly in the same way when head and gills are held in the water, and the body in air (Milne Edwards;) in both cases, without loss of weight. This fact shows that even if the weight of the animal be kept unaltered by the absorption of water through the body kept in that medium, yet the distribution of the fluids in the body does not take place in the proportion necessary for the preservation of their vital functions. The fish dies.

It is hardly necessary to remind the reader, that the experiments described in the foregoing pages, in so far as they permit us to draw conclusions as to the cause of the motion of the juices of the animal body, agree in all respects with the observations made on plants by Stephen Hales more than 120 years since.‖

The experiments of Hales on the mechanism of the motion of the sap, may stand as a pattern to all times of an excellent method. That they remain, to this moment, unsurpassed in the domain of vegetable physiology, may be, perhaps explained by the fact that they date from the age of Newton. They ought to be familiar to every vegetable physiologist.

In the beginning of his work, Hales describes the experiments which he made

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* The force urging the fluids towards the skin is equal to the difference of pressure acting on the skin.

† Liquids placed on the skin are absorbed by the evaporation of other parts.

‡ Effect of rubbing fat on a part of the skin or on the whole of it.

§ Fishes die in air, because the distribution of the fluids is prevented.

‖ Experiments of Hales on the motion of the sap in plants.

on the motion of the sap in plants in consequence of their evaporation in branches covered with foliage, in cut plants as well as in those still provided with roots.

He shows by the following experiment the influence of the mechanical pressure of a column of water, with and without the help of evaporation.

To a branch of an apple tree bearing its twigs and leaves, Hales fastened, air-tight, a tube seven feet long. He kept the branch with its twigs and leaves immersed in a large vessel of water, and filled the tube with water. By the pressure of the column of water, water was forced into the branch, and in two days the water in the tube had sunk 14¼ inches.

On the third day, he took the branch out of the water, and exposed it to free evaporation in the air. The water in the tube fell, in twelve hours, 27 inches.

To compare the force with which water is driven through the vessels of the wood, by pressure alone, with that produced by pressure and evaporation, he joined an apple branch, 6 feet long, with leaves, and exposed to the air, with a tube 9 feet long, which was filled with water.

From the pressure caused by the column of water, and by the evaporation going on at the surface of the twigs and leaves, the water fell (XIth experiment,) *in one hour*, 36 inches. He now cut off the branch 13 inches below the tube, and placed the portion cut off (with the twigs and leaves) vertically in a vessel of water. This last absorbed, in 30 hours, 18 ounces of water, while the portion of wood remaining in connection with the tube, which was 13 inches long, only allowed 6 ounces of water to pass, and that under the pressure of a column of 7 feet of water.

Hales shows in three other experiments, that the capillary vessels of a plant, alone, and in connection with the uninjured roots, are easily filled with water by capillary attraction, without, however, possessing the power of causing the sap to flow out and to rise in a tube attached.* The motion of the sap, concludes Hales, belongs to the evaporating surface alone; he proves that it goes on in an unequal degree from the stem, the twigs, the flowers, and fruit, and that the effect of the evaporation stands in a fixed ratio to the temperature and hygrometic state of the air. If the air were moist, but little were absorbed; the absorption was hardly perceptible on rainy days.

He opens the second chapter of his Statistics with the following introduction:—"Having in the first chapter seen many proofs of the great quantities of liquor imbibed and perspired by vegetables, I propose in this, to inquire by what force they do imbibe moisture. Though vegetables (which are inanimate) have not an engine, which by its alternate dilations and contractions, does in animals, forcibly drive the blood through the arteries and veins; yet has nature wonderfully contrived other means, most powerfully to raise and keep in motion the sap.

In his experiment XXI., he exposed one of the chief roots of a pear tree in full growth at a depth of 2½ feet, cut off the point of it, and connected the part of the root left in connection with the stem with a tube which he filled with water and closed with mercury.

In consequence of the evaporation from the surface of the tree, the root absorbed the water in the tube with such a force, that in six minutes the mercury rose to 8 inches in the tube. This corresponds to a column of water 9 feet high.

This force is nearly equal to that with which the blood moves in the great femoral artery of the horse. Hales, in his experiment XXXIV., found the force of the blood in various animals; "By tying those several animals down alive upon their backs, and then laying open the great left crural artery, where it first enters the thigh, I fixed to it (by means of two brass pipes which run one into the other) a glass tube of above 10 feet long, and ⅛th of an inch in diameter in bore. In which tube the blood of one horse rose 8 feet 3 inches, and the blood of another horse 8 feet 9 inches. The blood of a little dog 6½ high."

Hales showed by special experiments, that the absorbent force which he pointed out in the root is found also in the stem, in each separate twig, each leaf, and every part of the surface; and that the motion of the sap continues from the root towards the twigs and leaves, even when the stem has been entirely stripped of bark, inner and outer. This force acts not only from the roots in the direction of the summit but also from the summit in the direction of the root.

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* The motion of the sap is caused by the evaporating surface.

From his experiment he deduces the presence of a powerful attractive force residing in every part of the plant.

We now know, that this attractive force, as such, did not cause the rise of the mercury or water in his tubes, and it appears clearly from his experiments, that the absorbent power of plants, of each leaf, of each fibre of the root, is sustained by a powerful external force which is nothing else than the pressure of the atmosphere.*

By the evaporation of water at the surface of plants, a vacuum arises within them, in consequence of which water and matters soluble in water are driven inwards and raised from without with facility, and this external pressure, along with capillary attraction, is the chief cause of the motion and distribution of the juices.†

With respect to the absorbent power of the plant for gases, under a certain external pressure, his experiments offer the most beautiful evidence.‡ **Hales** says, in his experiment XXII., "This height of the mercury did in some measure show the force with which the sap was imbibed, though not near the whole force; for while the water was imbibing, the transverse cut of the branch was covered with innumerable little hemispheres of air, and many air-bubbles issued out of the sap-vessels, which air did, in part, fill the tube *e r*, as the water was drawn out of it; so that the height of the mercury could only be proportionable to the excess of the quantity of the water drawn off, above the quantity of air which issued out of the wood. And if the quantity of air which issued from the wood into the tube, had been equal to the quantity of water imbibed, then the mercury would not rise at all; because there would be no room for it in the tube. But if 9 parts of 12 in the water be imbibed by the branch, and in the mean time, but three such parts of air issue into the tube, then the mercury must needs rise near 6 inches, and so proportionably in different cases."

When, in his experiments, the root, the stem, or a twig had been injured at any part, by the cutting off of buds, root-fibres, or small twigs, the absorbent power of the remainder was diminished in a very obvious degree (because, from these places, by the entrance of air the difference of air was more easily equalized;)§ the absorbent power was greatest on freshly-cut surfaces, on which, however, it gradually decreased, till, after several days, it was not greater in these places than in the uninjured surface of the plant.

The evaporation, further, argues **Hales**, is the powerful cause which provides food for the plant and its vicinity. Disease and death of the plant follow, when the proportion between evaporation and supply is interrupted or destroyed in any way.‖

When, in hot summers, the earth cannot supply, through the roots, the moisture which during the day has evaporated through the leaves and surface of the tree, when the tree, or a twig of it, dries up, the motion of the sap is arrested at these points. When once dried, capillary action alone cannot restore the original activity; the evaporation is the chief condition of the life of plants; by its means a permanent motion, a continually repeated change in the quality of the juice (sap) is effected.

"By comparing," says **Hales**, "the surface of the roots of plants, with the surface of the same plant above ground, we see the necessity of cutting off many branches from a transplanted tree: for if 256 square inches of root in surface was necessary to maintain this cabbage in a healthy natural state; suppose upon digging it up, in order to transplant, half the roots be cut off (which is the case of most young transplanted trees,) then it is plain that but half the usual nourishment can be carried up, through the roots, on that account; and a very much less proportion, on account of the small hemisphere of earth the new-planted, shortened roots occupy; and on account of the loose position of the new-turned earth, which touches the roots at first but in few points."

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* The pressure rf the atmosphere is the active force.

† A partial vacuum is caused within plants by evaporation.

‡ The surface of plants absorbs gases.

§ The absorbent power diminished by injury to the plant.

‖ Evaporation provides food for the plant.

Hales proves the influence of suppressed evaporation by the following observations on hop-vines.

"Now there being 1,000 hills in an acre of hop-ground, and each hill having three poles, and each pole three vines, the number of vines will be 9,000; each of which imbibing four ounces, the sum of all the ounces, imbibed in an acre in a twelve hours' day, will be 36,000 ounces = 15,750,000 grains = 62,007 cubic inches, or 220 gallons; which divided by 6,272,640, the number of square inches in an acre, it will be found, that the quantity of liquor perspired by all the hop-vines, will be equal to an area of liquor, as broad as an acre, and $\frac{1}{101}$ part of an inch deep, besides what evaporated from the earth. And this quantity of moisture in a kindly state of the air is daily carried off in a sufficient quantity to keep the hops in a healthy state; but in a rainy moist state of air, without a due mixture of dry weather, too much moisture hovers about the hops, so as to hinder in a good measure the kindly perspiration of the leaves, whereby the stagnating sap corrupts, and breeds mouldy fen, which often spoils vast quantities of flourishing hop-grounds."

"This was the case in the year 1723, when ten or fourteen days' almost continual rains fell, about the latter half of July, after four months' dry weather; upon which the most flourishing and promising hops were all infected with mould or fen, in their leaves and fruit, whilst the then poor and unpromising hops escaped, and produced plenty; because they, being small, did not perspire so great a quantity as the others; nor did they confine the perspired vapor, so much as the large thriving vines did, in their shady thickets. This rain on the then warm earth made the grass shoot out as fast as if it were in a hot-bed; and the apples grew so precipitately, that they were of a very fleshy constitution, so as to rot more remarkably than had ever been remembered."*

"The planters observe, that when a mould or fen has once seized any part of the ground, it soon runs over the whole; and that the grass, and other herbs under the hops, are infected with it."

"Probably because the small seeds of this quick-growing mould, which soon come to maturity, are blown over the whole ground. Which spreading of the seed may be the reason why some grounds are infected with fen for several years successively."

"I have in July (the season for fire-blasts, as the planters call them) seen," says **Hales**, "the vines in the middle of a hop-ground all scorched up, almost from one end of a large ground to the other, when a hot gleam of sunshine has come immediately after a shower of rain; at which time the vapors are often seen with the naked eye, but especially with reflecting telescopes, to ascend so plentifully, as to make a clear and distinct object become immediately very dim and tremulous. Nor was there any dry gravelly vein in the ground, along the course of this scorch. It was, therefore, probably owing to the much greater quantity of scorching vapors in the middle than outsides of the ground, and that being a denser medium, it was much hotter than a more rare medium."

"This is an effect which the gardeners about London have too often found to their cost, when they have incautiously put bell-glasses over their cauliflowers early in a frosty morning, before the dew was evaporated off them; which dew being raised by the sun's warmth, and confined within the glass, did there form a dense, transparent, scalding vapor, which burnt and killed the plants."

When these observations are translated into our present language, we perceive with what acuteness and accuracy **Hales** recognized the influence of evaporation on the life of plants.

According to him the development and growth of the plant depends on the supply of nourishment and moisture from the soil, which is determined by a certain temperature and dryness of the atmosphere. The absorbent power of plants—the motion of their sap, depends on evaporation; the amount of food necessary for their nutrition, which is absorbed, is proportional to the amount of moisture given out (evaporated) in a given time. When the plant has taken up a maximum of moisture, and the evaporation is suppressed by a low temperature or by continued wet weather, the supply of food, the nutrition of the plant, ceases; the juices stagnate, and are altered; they now pass into a state in which they become a fertile soil for microscopic plants. When rain falls after hot weather, and is followed by great heat without wind, so that every part of the plant is surrounded by an atmosphere saturated with moisture, the cooling due to further evaporation ceases, and the plants are destroyed by fire-blast or schorching (*Sonnenbrand*, German, literally, sun-burn or sun-blight.)

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* Observations of Hales on the blight in hops and other plants.

After the experience and observations of so long a period in reference to the influence of evaporation on the condition of plants, I hardly think that any unprejudiced observer can entertain the smallest doubt concerning the cause of the great mischief which has befallen agriculture during the last few years.[*] If Hales, that unequalled observer and inquirer, had known the potato disease, I hardly believe that he would have ascribed it to an internal cause belonging to the plant, any more than he thought of ascribing the blight of the hop plants, formerly mentioned, to a special hop disease, or the rotting of the apples to an apple disease. Even Parmentier, to whom France is indebted for the introduction of the potato, knew this disease, and has very accurately described it.[†] The term "potato-rot" has been known to the oldest peasants and agriculturists since their youth; it has, doubtless, only acquired of late years the frightful significance, which seems to threaten the well being of nations, since the causes, which formerly brought it locally into existence, have spread over whole districts and countries. The writings of Hales bring to our century from a preceding one the consoling certainty (and this is especially important,) that the cause of this decay is not to be looked for in a degeneration of the plant, but depends on the combination of certain conditions accidentally coincident; and that these, when they are well ascertained and kept in view, enable the agriculturist, if not to annihilate, at least to diminish, their hurtful influence.[‡]

The potato plant obviously belongs to the same class of plants as the hop plant, namely, to that class which is most seriously injured by the stagnation of their juices in consequence of suppressed transpiration.[§] According to Knight, the tubers are not formed by swelling of the proper roots, but by the development of a kind of underground stalks or runners. He found that when the tubers under ground were suppressed, tubers were formed on the stalks above ground; and it is conceivable that every external cause which exerts a hurtful influence on the healthy condition of the leaves and stalks, must act in like manner on the tubers. In the districts which were most severely visited by the so-called potato disease in 1846, damp, cold, rainy weather followed a series of very hot days; and in 1847, cold and rain came on, after continued drought, in the beginning of September, exactly at the period of the most luxuriant growth of the potatoes.[‖]

In most places, no trace of disease was observed in the early potatoes before the middle of August; and even after that period low-lying, cold and wet fields, were chiefly attacked by it. In many plants, in the same field, in which the seed potatoes had been destroyed by putrefaction and decay, the tubers appeared quite healthy, while in others it was easy to see that these tubers alone, which lay next to the old potatoes, were infected and attacked by the disease, and that on the side next to the old tubers.[¶]

In 1846 all the potato plants in my garden died completely off towards the end of August, before a single tuber had been formed; and in 1847, in the same field, the tubers of all those plants which stood under trees, and in protected spots, were quite rotten, while no trace of disease appeared in spots which were more elevated and more fully exposed to the current of air. The cause of the disease is the same which, in spring and autumn, excites influenza; that is, the disease is the effect of the temperature and hygrometric state of the atmosphere, by which, in consequence of the disturbance of the normal transpiration, a check is suddenly, or for a considerable time, given to the motion of the fluids, which is one chief condition of life, and which thus becomes insufficient for the purposes of health, or even hurtful to the individual.[*]

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[*] The potato blight has probably a similar origin.

[†] The potato blight has been long known.

[‡] It is not due to a degeneration of the plant, but to a combination of external causes.

[§] The potato plant is one of those which suffers most from suppressed evaporation.

[‖] Character of the weather in 1846 and 1847, when the potato blight prevailed.

[¶] In most places the early potatoes escaped till after the middle of August.

The whole existence of a plant, the resistance which it opposes to the action of the atmospheric oxygen, is most closely connected with the continued support of its vital functions. The mere alternation of day and night makes, in this respect, a great difference. The sinking of the external temperature by a few degrees, causes the leaves to fall in autumn; and a cold night is followed by the death of many annual plants.

If we reflect that a plant, in order to protect itself from external causes of disturbance, or to seek the food which it requires, cannot change its place; that its normal vital functions depend on the simultaneous and combined action of water, of the soil, of the external temperature, and of the hygrometric state of the atmosphere; that is, on four external circumstances; it is easy to comprehend the disturbance of functions which must occur in the organism in consequence of any change in the mutual relations of so many combined agencies.[†] The state of a plant is a sure indication of equilibrium or misproportion in the external conditions of its life; and the dexterity of the accomplished gardener consists exactly in this, that he knows and can establish the just proportion of these conditions for each species of vegetable. Only one of these numerous conditions is in the power of the agriculturist, and that is, the production of the quality of the soil appropriate for the crop, including the necessary modification of its composition, by the mechanical working of the soil; by the irrigation or draining of the fields; and lastly, by the employment of manure. When one of the constituents of the soil, which, under the given circumstances, is necessary for the support of the vital functions, is absent, the external injurious influence is strengthened by this deficiency. Had this constituent been present, the plant would have been enabled to oppose to the external hurtful influences a continued resistance. One day may be decisive as to the life or death of a plant.[‡] An accurate knowledge of the influence exerted by the various constituents of the soil on the diseased condition, must enable the agriculturist to protect and preserve many of his fields for a long time from this destruction; but it is obvious that a universal remedy against this evil does not exist.

When the vessels of the plant are filled to overflowing with water, and the motion of the sap is suppressed, the nutrition, in most plants, is arrested, and death takes place. Every one knows the effect of a sudden or of a gradual overfilling of certain parts or organs, when the corresponding evaporation is suppressed. By the endosmotic pressure of the water flowing towards those cells, which contain sugar, mucilage, gum, albumen, and soluble matters in general, the juicy fruits and seeds approaching maturity burst, and the juice of grapes, cherries, plums, &c., passes, on contact with the air, into a state of progressive change. The fungi which have been observed on the potato plants and the putrefaction of the tubers, are not the signs of a disease, but the consequences of the death of the plant.[§]

Among the most important of the experiments made by Hales we must reckon undoubtedly those on the rise of the spring sap in perennial plants. His observations have been entirely confirmed by all those who since his time have studied the subject; but, in my opinion, without our having approached one step nearer to the cause of the phenomena.

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[*] The cause of potato blight is the same as that of influenza, and depends on the temperature and hygrometric state of the air.

[†] The life of plants is dependent chiefly on four external causes: only one of which, namely, the quality of the soil, in the power of the agriculturist.

[‡] Effects of the presence or absence of a single constituent of the soil.

[§] The plant dies, and fungi and putrefaction follow.

The most recent experiments on this subject by E. **Brücke**, leave no doubt in regard to the actual state of our knowledge.

According to **Dutrochet**, it is the extremities of the radical fibres, called by **De Candolle**, spongioles, which effect the rise of the spring sap; and he believes (L'agent immèdiat du mouvement vital, Paris,1826,) that the force with which the sap is driven upwards, acts from the root. **Dutrochet** cut off a peice of a vine stem, two metres long; and he saw that the sap flowed steadily from the shortened stem in connection with the root. When he had again cut it off close to the ground, he observed the portion in the ground continued to pour forth sap from the whole cut surface. He pursued the experiment, going deeper every time, and he always found that the sap flowed from the part left in the ground, till at last he came to the extreme points of the fibres, in which he then located the origin of the moving force.

The peculiar activity of the spongioles must, according to **Dutrochet**, be ascribed to all the causes, taken together, which determine the phenomena of endosmosis.

Now that we are better acquainted with the phenomena of what is called endosmosis, we may oppose to this view some well founded doubts. All observers agree, that the increase in volume of a liquid, separated from another liquid by a porous diaphragm, is determined by a difference in the qualities of the two liquids. If their composition and properties be the same, there is no cause sufficent to produce mixture and change of volume, since in this case, the attraction of both for the diaphragm, and for each other, is perfectly equal.

In the course of his admirable researches, **Brucke** determined the specific gravity of the spring sap which had flowed from the vine.* He found it, in one plant = 1·0008, and in another, = 1·0009.(1)

These numbers prove irresistably, that in the specific gravity of the sap of the vine is in no way different from that of ordinary spring water, or of the water which has filtered through garden mould. In most cases, spring water contains even more dissolved matter.

The spring sap of the vine, which had the sp. g. 1·0008, raised a column of mercury to the height of 174 lines (14·5 inches,) and therefore exerted a pressure equal to that of a column of water 195 inches high. It is quite impossible to account for this pressure by the difference in the amount of dissolved matter in the water absorbed by the roots, and the sap flowing from the cut surface. In the experiment No. IX., of **Brucke**, made with a vine, the sap of which had the sp. g. 1·0009 the mercury was raised at 7 A. M., to the height of 209 lines, (nearly 17·5 inches.

No one can doubt that what is called endosmosis has some share in the rise of the sap of the maple and birch trees, which is proportionally rich in sugar, and differs materially in composition from spring water, as well as on the flow or exudation of gummy or saccharine juices; but the pressure exerted in these cases, cannot be compared to that exerted by the sap of the vine, where the causes included under the word endosmosis cannot act.

It is evident, that the cause of the pressure of the spring sap must be transient, called into action by external causes, and limited to a short period.† The experiment of **Dutrochet**, from which he concludes that the cause of the rise of the sap resides in the extreme points of the roots, may be thus interpreted :—"The cause of the efflux and pressure of the sap exists in all parts of the uninjured plant, down to the extreme spongioles of the root."

The present season does not admit of experiments on this point; but as spring approaches, it may be proper here to develope more clearly the grounds of the opinion, that the cause of the efflux of the sap of the vine is a transient one. Perhaps some one may thus be induced to decide experimentally all the questions of this remarkable phenomenon.

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(1) Poggendorf's Annalen der Physik, lxiii. 177.

* Observations of **Brucke** on the specific gravity of the sap of vines.

† The cause of the rise of the sap is transient; and depends on external influences

Hales, in his experiment XXXIV., cut off a vine stem 7 feet above the ground, and attached to the trunk tubes of 7 feet long, joined together. Below the cut there were no branches. This was done on the 30th of March, at 3 P.M.

As the stem poured out no sap on that day, he poured water into the attached tube to the height of two feet.

This water was absorbed by the stem, so that about 8 P.M., the water had fallen to 3 inches in the tube.

The next day, ½ past 6 A. M., the sap stood 3 inches higher than at 8 the evening before. From this time the sap continued to rise, till it reached a height of 21 feet. It would perhaps, says **Hales**, have risen higher, had the joinings of the tubes been more water-tight.

Whatever opinion we may entertain as to the cause of the efflux and pressure of the sap, it is impossible to suppose that the mechanical or any other structure or quality of the radical fibres, the spongioles, or the inner parts of the vine stem generally, can have changed so much between the evening of the 30th and the morning of the 31st, as to give rise to two completely opposite influences.

On the evening of the 30th the water poured into the tube was absorbed ; on the 31st it was expelled with a continually increasing force.

In his experiment XXXVII., **Hales** fixed, on three branches of a horizontally trained espalier vine, siphon tubes, filled to a certain point with mercury.

The three branches received their sap from the common stem, that stem from the root. The first branch was 7 feet from the second, the second 22 feet inches from the third. The first and third branches were two years old, middle one was older.

From the 4th to the 20th of April, the mercury stood, in consequence of pressure of the sap, higher in the open limb of the tubes than in the other wh was attached to the branch.

The greatest height attained by the mercury was from 21 to 26 inches.

On the 21st of April, when the flowering was nearly over, the sap in the mid branch went backwards ; it was absorbed, and so considerably, that the merc stood 4 inches lower in the open limb than in the other. After a rainy night on the 24th of April, the sap again rose in the open tube 4 inches.

In the first (lowest) branch, the sap went back on the 29th of April, 9 days after the middle one ; the third (highest) branch only began to absorb the sap on the 3d of May, thirteen days after the middle one.

We see from this experiment, as **Hales** observes, "That the cause which produces the flow of the sap does not proceed from the root alone, but that it belongs to a force inherent in the stem and branches. For the middle branch followed more rapidly the changes of temperature, of dryness and of moisture, than the two others, and absorbed the sap nine days before one, and thirteen days before the other, both of which, during this time, poured out sap instead of absorbing it. (The cause of the efflux and pressure had, in the older branch, disappeared, and given place to an opposite influence, while it still continued active in the two younger branches.)

"The middle branch was 3 feet 8 inches higher than that next the stem. The height of the mercury in the three tubes was, respectively, 14½, 12½, and 13 inches. The maximum was 21, 26, and 26 inches. These numbers prove that the greater length of the middle branch had no perceptible influence on the height of the mercury, as compared with that in the other tube."

In his experiment XXXVIII., **Hales** observes,—"Moisture and warmth made the sap most vigorous. If the beginning or middle of the bleeding season, being very kindly, had made the motion of the sap vigorous, that vigor would immediately be greatly abated by cold easterly winds.*

"If in the morning while the sap is in a rising state, there was a cold wind with a mixture of sunshine and cloud ; when the sun was clouded the sap would immediately visibly subside, at the rate of an inch in a minute for several inches, if the sun continued so long clouded ; but as soon as the sunbeams broke out again, the sap would immediately return to its then rising state, just as any liquor in a thermometer rises and falls with the alternacies of heat and cold; whence it is probable, that the plentiful rise of the sap in the vine in the bleeding season, is effected in the same manner."

---

* Effect of cold and of shade on the rise of the sap.

If we consider, that the sap in spring, even with a clouded sky, does not cease to rise and flow, for this even goes on during the night, we cannot explain the fall of the sap from the moment that the sun was covered by a cloud by a mere change of temperature in the juice, because the time was too short for the cooling and contraction by cooling (one inch in a minute.)* Heat determined the more rapid rise, and cold the fall, but they acted on a cause which lay higher than the root, and which was more sensitive to heat than the liquid itself.

Hales says, in his experiment XXXVIII.—"In very hot weather many air bubbles would rise, so as to make a froth an inch deep, on the top of the sap in the tube.†

"I fixed a small air pump to the top of a long tube, which had twelve feet height of sap in it; when I pumped, great plenty of bubbles arose, though the sap did not rise, but fell a little, after I had done pumping."

In his experiments on the amount of air absorbed by plants, chapter V., he observes, "in the experiments on vines, the very great quantity of air which was continually ascending from the vines, through the sap in the tubes; which manifestly shows what plenty of it is taken in by vegetables, and is perspired off with the sap through the leaves."

When we take these facts into consideration, the opinion appears not untenable, that the incomprehensible force, which causes the sap of the vine to flow in spring, may be simply referred to a disengagement of gas which takes place in the capillary vessels (filled with liquid, and keeping themselves constantly full,) in consequence of a kind of germination; and it is possible that the height of the column of mercury, or of water, is only a measure of the elasticity of the disengaged gas.‡

Let us suppose a strong glass bottle, in the mouth of which a long tube, open at both ends, and reaching to the bottom, is cemented, to be filled with a liquid in which, from any cause, a gas is disengaged (solution of sugar mixed with yeast, for example,) it is evident that the liquid must rise in the tube from the separation of the gas. When it has risen to 32 feet, the gas will occupy only the half, and at 64 feet, one third of its volume under the usual atmospheric pressure. In this case, the height of the liquid in the tube is no measure of a special power residing in the walls of the vessel; it only shows the tension of the gas.

If the walls of the vessel were permeable to the gas under a certain pressure, no further rise, beyond that point, could occur.

If, in the apparatus, Fig. 4, we push the tube *a* through the cork down to the little lead drop; if we then fill the tube *c* with water to which some yeast has been added, and *a* with solution of sugar, and expose the whole to a temperature of from 68° to 75°, the liquid rises in *b*, from the gas disengaged in *c*, very rapidly, so as to overflow. If *c* be filled with solution of sugar, and *a* with yeast, the same rise occurs, and lasts till the disengaged gas puts an end to the contact between the membrane and the liquid

It is hardly necessary to point out, that the idea above expressed as to the cause of the flow and pressure of the spring sap, is nothing more than an indication of the direction in which experiments must be made. When we know with accuracy the volume of the liquid which flows out of a vine at the time of flowering, and the quantity of gas which is developed at the same time, we shall, I trust, find ourselves a step nearer to the explanation of this phenomenon. According to the experiments of Geiger and Proust, the sap of the vine is rich in carbonic acid; and it is possible that the gas which is disengaged, may be no other than carbonic acid gas.

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* How is this effect to be accounted for?
† Gas is given off with the sap.
‡ The rise of the sap may, therefore, be caused by the evolution of gas.

APPENDIX.

ON THE NATURE AND PREVENTION OF THE POTATO DISEASE.

After the preceding pages were in print, I received from Baron Liebig a copy of the Journal of the Agricultural Association of the Grand Duchy of Hesse, (Darmstadt,) No. 7, dated 15th February, 1848, containing the account of a method proposed by Dr. Klotzsch (Keeper of the Royal Herbarium, Berlin, and a distinguished Botanist and Vegetable Physiologist,) for preventing the ravages of the potato disease. The proposal of Dr. Klotzsch, and his views as to the nature of the disease, are such as materially to strengthen the opinions expressed on this subject by Baron Liebig, (see pp. 87, seq.) As a knowledge of the method suggested by Dr. Klotzsch is likely to be interesting to many of the readers of this work, I have thought it right to give it in an Appendix.

William Gregory.

METHOD PROPOSED BY DR. KLOTZSCH, FOR THE PROTECTION OF THE POTATO PLANT AGAINST DISEASES

The potato, which is an annual plant, represents, in the tubers developed from the stem, the perennial part of a plant. For while the duration of its development is analogous to that of annuals, its functions coincide exactly with those of dicotyledonous shrubs and trees.

"The potato plant differs from all those plants which are cultivated for economical purposes in Europe, and can only be compared to those orchideous plants which yield salep, and which are not yet cultivated among us.

"The tubers, both of the potato and of the salep plants, are nutritious, and agree in this, that in the cells of the tubers, grains of starch, with more or less azotized mucilage, are collected, while the cell walls possess the remarkable property of swelling up into a jelly, and thus becoming easily digestible, when boiled with water.

"But while the tuber of salep contains only one bud, or germ, the potato usually develops several, often many, germs.

"The potato plant, like all annuals, exerts its chief efforts in developing flowers and fruit. Like all annuals, too, it has the power of shortening this period of development, when the power of the roots is limited; as also of lengthening it when the extent and power of the roots are increased.

We observe in nature that plants with feebly developed roots often have a weak, sickly aspect, but yet come to maturity in flower and fruit sooner than stronger individuals, well furnished with roots.

"In perennial plants we observe a second effort, which is directed towards preparing and storing up nutritious matter, for the consumption of the plant. The preparation of this nutriment is effected by the physiological action of the leaves, under the influence of the roots. The stronger and larger the former are, the more is this preparation of food delayed.

"The nutritious matters are stored in the colored stratum of the bark in shrubs and trees, and in the tubers in the potato and salep plants. Not only, however, the nutrient matters, but also the cells, owe their origin to the physiological action of the leaves.

"On considering these things, it follows, that the potato plant requires more care than is usually devoted to it. Hitherto the whole cultivation consisted in clearing off weeds, and hoeing up the earth round the stems. Both of these measures are, indeed, necessary, but they are not alone sufficient; for the plant is cultivated, not on account of its fruit, but for the sake of its tubers, and our treatment should be modified accordingly.

"The chief points to be attended to, with a view to the attainment of this object, namely, the increase of tubers, are—

1. To increase the power in the roots, and
2. To check the transformation which occurs in the leaf.

"We obtain both ends simultaneously, if, in the 5th, 6th, and 7th week after setting the tubers, and in the 4th and 5th week after planting out germs furnished with roots, or at a time when the plants reach the height of 6 to 9 inches above the soil, we pinch off the extreme points of the branches or twigs to the extent of half an inch downwards,* and repeat this on every branch or twig, in the 10th and 11th week, no matter at what time of day.

"The consequences of this check to the development of the stem and branches, is a stimulous to the nutrient matters in the plant in the direction of the increase, both of roots and of the multiplication of the branches of the stem above ground, which not only favors the power of the root, but also strengthens the leaves and stalks to such a degree, that the matters prepared by the physiological action of these parts are increased and applied to the formation of tubers, while at the same time the direct action of the sun's rays on the soil is prevented by the thick foliage, and thus the drying up of the soil and its injurious consequences are avoided.

The checking of the transformation in the leaf is equivalent to the interruption of the natural change of the leaves into calyces, corollæ, stamens, and pistils, which is effected at the expense of the nutrient matters collected in the plant; and these, when this modification of the leaves is arrested, are turned to account in the formation of tubers.

"Led by these views, I made, in 1846, experiments on single potato plants, carefully marked by pinching off the ends of the branches. They were so readily distinguished in their subseqnent growth from the plants beside them, by more numerous branches, larger and darker foliage, that in truth no marking was necessary.

"The produce from these plants of tubers was abundant, and the tubers were perfectly healthy; while the plants next them which had not been so treated, gave uniformly less produce, at the same time the tubers were rough on the surface, and in many instances attacked with the prevailing disease. This experiment was incomplete, and did not give a positive result, but it was yet encouraging for me.

"In the middle of April, 1847, an experiment was made on a low-lying field with the round white potatoes, generally cultivated here, a variety which had not suffered much from the disease which first appeared here 1845. The potatoes were planted in the usual way by an experienced farm servant.

"After weeding them in the end of May, I renewed my experiment by pinching off the points of the branches of every second row, and repeated this in the end of June. The result surpassed all expectations. The stocks of the plants not treated

on my plan, were long, straggling, and sparingly furnished with leaves, the leaves themselves, small and pale green.

"In the next field, potatoes of the same variety were planted on the same day and left to nature. They appeared in the first six weeks healthy, even strong, but gradually acquired a poor aspect as the time of flowering and fruit approached, and finally, exhibited precisely the same appearance as the rows not treated by pinching off the extremities in the field in which my experiments were made.

"The harvest began in the surrounding fields in the middle of August, and was very middling. The tubers were throughout smaller than usual, very scabby, and within these fields, to a small extent, attacked by the wet rot.

"In the end of August, the difference between the rows treated by me and those not treated, became so striking that it astonished all the work people in the neighborhood, who were never tired of inquiring the cause. The stocks of the rows left to themselves were all now partly dried, partly dead. On the contrary, the rows treated as above were luxuriant and in full vigour, the plants bushy, the foliage thick, the leaves large and green, so that most people suppposed they had been later planted.

"But the difference in the tubers was also very decided. The tubers of the plants in the rows treated on my plan were not, indeed larger, but vastly more numerous, and they were neither scabby nor affected with any disease whatever. A few had pushed (which was to be ascribed to a late rain,) and were apparently incompletely developed, while scab and wet rot attacked more and more the tubers of the other plants, which also fell off on the slightest handling.

"Although I am far from believing that I am able to explain the nature of the potato disease which has visited us of late years, yet I feel certain that I have discovered a means of strengthening the potato plant to such a degreea s to enable it to resist the influences which determine such diseases.

"Should any one be deterred from continuing the cultivation of potatoes, on account of the manipulation here recommended, which may be performed by women and even by children, I would remind him that the same field planted with potatoes is capable of supplying food to twice as many persons as when employed to growing wheat."—*From the Annals of Agriculture in Prussia, edited by the College of Rural Economy.*

Dr. Klotzsch presented to the King of Prussia a memorial offering to give to the world his method of preventing disease in potatoes, provided he were assured of a remuneration of 2,000 dollars, (about £300,) if, after three years experience it should be found efficacious.

The King handed the memorial to the Minister of the Interior, who requested the College of Rural Economy to discuss the matter with Dr. Klotzsch.

The president of the college undertook the arrangement, and, after Dr. Klotzsch had explained to him privately his method, reported most favorably of it to the College, which unanimously recommended that the very moderate remuneration asked for by Dr. Klotzsch should be secured to him on the following conditions, which were accepted by him.

1. That the College of Rural Economy should be the judges of the efficacy of the proposed method.
2. That their decision should be given, at latest, within three years, provided the potato disease against which the plants are to be protected, should appear during that period.

The Minister of the Interior approved of the recommendation, and authorized the College to conclude an agreement with Dr. Klotzsch.

The agreement has been concluded, and now the method is published that it may be tried and tested as widely as possible by comparative experiments, similar to those made by Dr. Klotzsch himself. The cost of it is stated not to exceed 1*s.* 6*d.* per acre in Germany.

It is very desirable that this method should be tried in the British Islands, and as the season for trying it now approaches, I have here given Dr. Klotzch's account entire.

William Gregory.

THE END.

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* Any one would be bitterly disappointed, who on the principle, that "there cannot be too much of a good thing," should take off more than is here recommended, in order to use it as fodder.

End of Volume

Volume:
5

CHEMISTRY AND PHYSICS

IN RELATION TO

PHYSIOLOGY AND PATHOLOGY.

BY BARON JUSTUS LIEBIG, M.D., P.H.D., F.R.S., M.R.I.A.

AUTHOR OF "AGRICULTURAL CHEMISTRY," "ANIMAL CHEMISTRY,"
"MOTION OF JUICES IN ANIMAL BODY, AND CURE OF THE
POTATO DISEASE," "LETTERS ON CHEMISTRY,"
"FIRST" AND "SECOND SERIES," "CHEMISTRY OF FOOD," ETC., ETC.

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CHEMISTRY AND PHYSICS

IN RELATION TO

PHYSIOLOGY AND PATHOLOGY.

DEVELOPMENT OF THE NATURAL SCIENCES.

THE history of science teaches us, that every branch of physics comprised at its commencement nothing beyond a series of observations and experiments, which had no obvious connection with each other.

SPECIAL LAWS OF NATURE.

All advances in science were dependant upon the discovery of new facts, by which two or more previously observed experiments were made to bear upon each other. The first step gained was the deduction of *special* laws, which embraced in themselves the connection of a certain number of natural phenomena; the next was the attainment of *general* laws, or what was the same thing, of certain expressions of the dependence or connection of a larger, or smaller series of experiments.

GENERAL LAWS OF NATURE.

Many branches of physics as mechanics, hydrostatics, optics, acoustics, the theory of heat, &c., have been elevated to the rank of abstract sciences, in consequence of their permitting all known cases of the phenomena of motion, air, sound, heat, &c., to be traced through a series of syllogisms to certain truths, or to a very small number of undoubted facts, which not only unite together those already known, but also those yet remaining to be discovered; so that a new isolated series of conclusions is not requisite to the explanation of new phenomena, or experiments.

If we can regard it as undoubted that not only the phenomena of inanimate nature, but also, those of animal and vegetable life, are peculiar to themselves, stand in certain relations to each other, and depend upon certain causes; and if further, it be true that it is only by a knowledge of these causes or conditions that we can gain a clear insight into the existence of organic processes, then must the investigation of the reciprocal dependence and the conditions of the phenomena of life, be regarded as the most important department of physiology.

The explanation of many natural phenomena, requires, in most cases, nothing more than an acquaintance with the relation of dependence in which they stand, one to the other.

The knowledge of these relations is attainable in every branch of natural investigation by the extension of experience, and by correctness of observation; and there can be no question that, at some future time, as chemistry loses the character of an experimental art, so will physiology be capable of ranking as a deductive science.

COURSE OF INVESTIGATION.

If it follow, according to the course of natural investigation, that general laws must be preceded by those that are merely special, and it be granted that a just conception of life cannot be acquired without a thorough knowledge of the organim in all its parts, both with reference to the functions of individual organs in themselves, and their mutual dependence, including the consideration of the relation of form to organic matter; then it will not be denied that we are still most widely removed from the possession of a general formula, embracing the comprehension of life, and the knowledge of the causes and connections existing in natural phenomena. So remote is this object, that there are many who still regard the probability, or even possibility of the attainment of such general laws in physiology, as purely chimerical; while most persons are unable to distinguish psychical from corporeal phenomena, or the idea of vital power from the form of living organs.

PRECONCEIVED VIEWS, AN IMPEDIMENT TO INVESTIGATION.

A man even of the most cultivated mind cannot wholly emancipate himself from the dominion of those laws, on which his powers of comprehension are dependant. If the daily experience of a prolonged period constantly show him two phenomena or facts, apparently closely connected together, if he learn that, for centuries, they have been considered inseparable, and if he have never, either by accident or design, been led to consider each individually, he becomes gradually incapable, in spite of the greatest exertion to the contrary, of considering them apart, until at length his mind refuses to admit the very assumption of any difference existing in the nature of the phenomena observed.

Innumerable instances testify that even the most accurate observers of their age have regarded certain facts or representations as impossible, simply because their power of comprehension was unable to receive them; while their successors have not only comprehended them, but what is far more, have universally received them as incontestible truths.

Men of the clearest discernment, who were raised far above ordinary ideas, were yet unable to understand that the force of gravity acts with an upward instead of a downward tendency, or that the sun from its vast distance could exercise any influence upon the earth, or the earth upon the moon. Even the great Leibnitz rejected the Newtonian theory, because he could not regard it as possible that the planets could maintain a motion in a curved line around one common centre, without the agency of some continuously acting mechanism; since according to him in the absence of a propelling power, the body must fly off at a tangent to its orbit.

Starting from the general proposition that a body can exercise no influence upon a point, with which it is not in contact, the Newtonian theory of gravitation was rejected; and the fact now become familiar to the mere schoolboy, that the power of gravitation is active at boundless distances without any influencing material agent, appeared even to men of the noblest intellect to contain so great a contradiction, that rather than receive it, they maintained the probability of the strange, and unfounded creations of their own fancy.

There are many theories in mechanics and physics, which, although we know to have been regarded as the great discoveries of their age, and the results of the most patient and laborious investigations, appear to us now so true and obvious, that if we did not possess the history of their gradual development, it would seem incredible that a doubt of their truth could ever have been entertained by any individual in any age.

The simple position that a body once put in motion, could traverse space, forever pursuing with unvarying velocity the same direction, appeared so opposite to common and evident experience that the recognition and establishment of its truth met for a long period with the greatest opposition.

That two chemico-active bodies can form a combination of definite unchangeable properties, through their union in indefinite or unlimited proportions, appears, even to our sound powers of comprehension to be untenable.

The comprehensive has, as we have shown, nothing to do with the apparent, but is dependant upon the condition of our mental development. If the uniting link that associates a fact with the usual course of our ideas be wanting, the fact itself will appear devoid of truth and comprehensibility. This is one of the greatest impediments that stands in the way of the application of chemistry to psychology, and of a simple consideration of chemical discoveries on the part of many physiologists; and if to this be associated, as in pathology, the assumption of facts on experience, the correctness of which has no other foundation than the opinion of many centuries, and if, in these branches of science, the mode of arriving at conclusions and deductions be not changed, there is no hope as yet, that chemistry, with all her advances, will ever be able to render any essential aid to physiology and pathology; while it is alike impossible for either of these sciences to attain to any scientific basis, without the co-operation of chemistry and physics. While no one doubts the necessity of this co-operation, there is little unity of sentiment regarding its practical application.

PHYSIOLOGY AS A DEDUCTIVE SCIENCE.

The opinion that every empirical science, including physiology, may, in the course of time, acquire the character of a deductive science, seems to require no confirmation; and it must be immaterial whether this position be attained by borrowing from other sciences: as for instance, in the case of astronomy, which owes its scientific basis to its partial incorporation with the theory of motion.

INVESTIGATION PURSUED ACCORDING TO PHYSIOLOGICAL LAWS.

If we bear in mind that, as no occurrence in the world, so also no phenomenon of nature, either in the animal or vegetable kingdom, can appear without standing in relation to, or as the immediate result of another, that has preceded it: (as the present condition of a plant or animal is dependent upon certain pre-existing conditions;) it is clear, that if all the causes that affect one condition and their influence upon time and space, with their properties, are known to us, we shall be able to declare what other condition will succeed the former one. The expression of these conditions or relations, is what we term a natural law.

THE DIFFERENCE BETWEEN THE CHEMISTRY OF THE PRESENT DAY AND THAT OF AN EARLIER AGE.

No one who is conversant with the history of the development of chemistry, and of many other branches of physics, will deny that the main reason of the advance of these sciences rests upon the gradually confirmed conviction that every natural phenomenon has more than one requirement, every effect more than one cause, and that it is the simple inquiry into the plurality of these conditions, and the separation of effects which distinguish the chemistry of the present day from that of former times. A speedy termination was put in the period of phlogosis to all research by assuming principles of dryness and humidity, heat and cold, combustibility, acidity, volatilization, &c.; ascribing a special essence to every property, the explanation of which was included in the simple description of the phenomenon.

The fluctuation in weight which bodies manifest on being submitted to chemical processes, was regarded as a property of matter similar to the effervescence of limestone, when acted upon by acids. There was a theory for the respective phenomena of combustion and calcination, although the relations of weight were not regarded as in the province of earlier chemistry. It was left to physiologists to explain how a body could have an increase of weight after losing one of its constituents; and further, how under any circumstance, a body can show a fluctuation in weight. The increase of weight in calcination was an accidental property, peculiar as it was supposed, together with many others, to metals.

POINT OF VIEW ASSUMED BY MANY PHYSIOLOGISTS OF THE PRESENT DAY.

Many physiologists and pathologists still regard the conception of vital processes and phenomena, from the same point of view as the phlogistics; they ascribe the effects of the nervous system to a nervous force; while vegetation, irritability, sensibility, action and reaction, simple effects of motion or resistance, causes of the formation and the change of form, which are included in the expression of typical forces, are all regarded as *entities*, and assume the place occupied in older chemistry by the essences.

CONFUSION OF EFFECT AND CAUSE.

The most common phenomena have been incorporated in the minds of many physiologists as actual capacities—properties—which they have falsely been led to explain by especial reasons, different from the others known; thus the terms endosmosis, and exosmosis, have been applied to the return to a state of equilibrium of two fluids differing in their nature, or of two unequally dissolved substances, separated by an animal membrane; and thus we continue to treat names as if they were facts, embracing an explanation of the process, while this phenomenon is nothing more than a filtration, differing so far from other forms, that the permeation is dependant not upon pressure, but upon attraction, disposition, or affinity.

To this mode of observation was added the equally great error of conceiving that causes must be of a similar nature to their results, and that like must call forth like. Thus, the cause of combustion was thought to be something combustible, and the cause of acid, something acid; the caustic property of burnt lime was derived from a caustic, which suffered itself to be transferred from one body to the other, from the lime, for instance, to the so-called mild alkalies; the presence of a primitive alkali was pre-supposed in the alcalies; an *acidum universale* in acids; a primitive salt in salts; while analogous bodies were varieties of *one substance.*

FALSE EXPLANATION OF PHYSICAL PROPERTIES.

Many physical properties of bodies were explained by the physical character of their most minute parts; thus, for instance, a sharp taste was ascribed to sharp particles. Lemery's* view that the smallest atoms of an acid were lance-shaped, and that the atoms of alkalies were porous like a sponge, met with great approval, for it seemed to confirm their mutual power of neutralization; and the fact of ammonia precipitating gold in its solution was a convincing proof to the chemists of that day, of the capability they ascribed to ammonia of abrading the lance-like points of the atoms; it acted, to use Lemery's words, like the cudgel thrown by a boy against a nut tree laden with fruit.

Thus certain substances which possess an astringent or cooling flavor, were supposed to exercise an astringent or cooling effect upon the living body; and any alcoholic drink, which may be termed strong according to the common mode of speech, was admitted as a tonic among other remedial agents.

It is an error to suppose that this mode of considering natural phenomena belongs to a very remote period, as will be seen from the following extracts drawn from Mulder's "Chemistry of vegetable and animal Physiology."† "We, therefore, rightly conclude," he observes, "that in sulphur, selenium, chromium, and manganese, similar forces exist; and thus we arrive at the idea that the chemical relations of these elements are not dependant upon their matter, but upon the analogous forces, by which their molecules are governed. Thus the idea of the matter of sulphur is associated what somewhat of the idea of force, and of the same force which operates in selenium also—which operates not only in forming combinations, but in contributing likewise to the formation of the whole character of the compound substances produced. We remark the effects of this force which exists in sulphur, selenium, &c., even in more complicated compounds than those to which we have referred."

The excellent investigations of Mitscherlich and Kopp upon isomorphism, have not been able, as we see, to eradicate this mode of observation.

EVERY PHENOMENA OF NATURE IS DEPENDANT ON MORE THAN ONE CAUSE.

The truth of a number of opinions or views, whether justly or unjustly, is liable to be doubted; but a phenomenon, an effect, cognizable to the sound senses of the most different persons, every where, and at all times, cannot be doubted, excepting inasmuch as the causes which bring about certain results may not be fully known. But this cause can never be supplied by the imagination, in the department of natural investigation; for we know that one and the same effect, as, for instance, a mechanical motion, a blister upon the skin, or the contraction of a

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*Lemery's opinions were first promulgated in his *Cours de Chimie*, published in 1675. An English translation entitled, *A course of Chymistry, containing an easy Method, &c.*, passed through four editions, the last bearing the date of 1720.

† "Versuche einer allgemeinen physiologischen Chemie." Braunschweig, 1844, p. 37, of the first edition.

muscle, may be brought about by different causes, and that one and the same cause may bring about a variety of effects.

CHEMICAL COMBINATION.

We know that the simple process of chemical combination is dependant upon at least three causes or conditions, which must stand in certain relation to each other, if the combination is to be formed, and that affinity, the force of cohesion, and heat, have an equal share in the process.

DIFFERENT EFFECTS OF HEAT.

We know further that when a given quanity of heat expands a solid body, and forces its minutest parts to separate from each other, a double or triple quantity will entirely change the properties of the body, and that a further alteration occurs in these properties if the amount of heat that is communicated exceed a certain degree.

It is perfectly certain that expansion, liquefaction, and transition into the gaseous form are dependant upon causes, identical in their nature, but that the effects produced are by no means proportional to the causes; the reason of this has been justly sought in the reaction or resistance of some other cause, and our idea of the existence of the power of cohesion thus acquires a more scientific basis.

The same degree of heat, which is a condition of the combination of the oxygen of the air with mercury, produces the opposite effect—the decomposition of the oxide of mercury into mercury and oxygen, if the temperature be raised a few degrees.

By a simple process of oxidation we derive acetic acid from alcohol: we obtain this acid from the oxidation of salicylite of potash; we may also exhibit it from wood, sugar, and starch, by the mere application of heat and the exclusion of the oxygen of the atmosphere: in all these cases the product yielded is the same; but the conditions of its formation are extremely different.

THE SEPARATION OF VITAL EFFECTS, AND THE CHIEF REQUISITES THERETO.

If it be true that physiology can only attain to a scientific basis by the investigation of the plurality of conditions, on which the phenomena of life depend; and if it be granted that this can only be attained by a consideration and separation of vital effects, and the conditions to which they give rise; it is evident that since a number of causes have, or may have, an influence upon these effects, the physiologist ought to possess an intimate knowledge of all the forces and causes which may bring about changes of form and character in matter; since, without this, he would be unable to separate true effects from those which might be erroneously ascribed to the cause, and which, perhaps, have nothing in common with indications of gravity, affinity, &c.

CONTINUED DISREGARD OF THESE PRINCIPLES.

No one can deny that these principles are applied in the investigations of pathology at the present day, and the difference between the method of inquiry now pursued from that in use in the earlier stages of philosophical science is certainly very great, although the influence of the older system is not quite exterminated, at least as far as Germany is concerned. In spite of our acknowledgment of the accuracy of the principles of natural investigation, we are but too ready to throw off its shackles, and suffer our unfettered thoughts wherever the way is not clear, to erect a barrier of errors before the gates of knowledge. Favorite antitheses and paraphases still play a chief part in all explanations, robbing common facts and conditions of the simplicity and perspicuity of which they are capable. The deficiency here rests not with the principles, but in the want of their due application.

EXAMPLES.

A few extracts from the writings of a distinguished pathologist of the present day will suffice to justify these remarks, and to show the influence that the older mode of investigation still exercises upon the present; they will also tend to demonstrate how impossible it is to arrive at correct conclusions by starting from indefinite ideas, and how small is the acquisition of scientific knowledge with reference to chemical and physical sciences, even in the most intellectual men.

INDEFINITE IDEAS OF IRRITABILITY AND IRRITANTS.

Many external causes, as the atmosphere, heat, electricity, magnetism, chemical agents, mechanical pressure, friction, &c., exercise certain effects upon the whole, or parts of the organism; in some cases these are similar, in others different.

These effects are dependent upon a certain number of those active causes, which exert either an external or internal influence upon the organism. The existence of these causes is capable of being defined and measured by the qualitative and quantitative difference in the effects produced by external causes which indicate a changed condition. The active forces in the organism are, accordingly, appreciable by the investigation of those effects which are qualitatively and quantitatively modified by every external cause. The method pursued by modern pathology is exactly the reverse of the principles advanced, as is proved by a few passages from the celebrated work of Henle, "On Pathological Investigations."* "Irritability is," according to Henle, "every thing which, in acting upon organic matter, alters its form and composition, and consequently its function," p. 223. Far from regarding the separation of causes and their effects as the indispensable auxiliaries of knowledge, the author here, as we perceive, includes all imaginable causes of the changes in the form and properties of the organic body, under the term irritability; and, in the exposition of conditions, this word plays the part of an entity, although this does not comprehend the mode of action of electricity, heat, light, magnetism, or chemical forces, but simply a small part of the action of each of these agents. We need only apply to the following, the definition given above by this author, to perceive how little science gains by such a method.

"Irritability alters the nervous fibre and its relations to the blood; but if it do not wholly decompose it, the metamorphosis of matter continues, and is, perhaps, even increased by the irritation, &c."

FALSE ANALOGIES.

No one after this will wonder to find, at p. 221 of the same work, an hypothesis regarding the mode of action of irritants, although there is not an illusion to the mode of action of any thing, or cause, which in acting upon organic matter changes its form or composition.

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*Pathologishe Untersuchungen, Berlin,1840.

TYPICAL FORCE—AN INDEFINITE IDEA.

It cannot surely be correct to regard certain vital indications, (as, for instance, the development of the organism from the egg or germ, or the renewal of original forms,) as dependent on a certain typical power in the organism, since this expression is nothing but a mere verbal illustration.

Henle, at page 129 of his "Rationelle Pathologie," admits that the perpetual typical laws, which he has spoken of, are inadequate to explain how the salamander can regenerate a whole limb, while in the kindred frog regeneration is limited to a few tissues, as in the higher animals; and regards these indications as proving nothing more than the fact that they are such. To comprehend an explanation, presupposes a knowledge of the laws on which it depends, and the comprehension of the law is inseparable from the knowledge of qualitative or quantitative relations.

By way of rough illustration, we may compare the healthy organism in many respects to a large Transatlantic steamboat; the latter consumes at every moment of its passage oxygen and fuel, which are again given off in the form of carbonic acid, water, soot, or smoke; it encloses sources of heat and power, which call forth motor effects, and minister to the wants of the crew, by preparing food for their use. If a sail be rent, there is one at hand to repair it; if a leak be sprung, the joiner is there to arrest the damage; while a number of men are ever active in keeping up the original condition of the vessel, and maintaining her speed; and so it is with the living body, which likewise has *its* smiths, and joiners, and other artificers. Let it then be our duty to study and recognise its mutual relations.

LIGHT CONSIDERED AS AN IRRITANT.

It is impossible to arrive at the comprehension of a subject, if, as is done by some pathologists, a term—such as an irritant—be made to include alike active causes, which change the form and composition of organic bodies, and such as light, sound, &c., which do not possess this capacity. Light is in itself a motor appearance, and as such is perceived by the eye, exciting in the optic nerve a motion which is transferred to the sensorium; the motion once begun is continued, as the tones of a flute are prolonged in the air, or a string in the piano produces tones. The impression of light is motion itself, but this motion calls forth no change in the form and composition of the eye or brain, unless new causes are superadded; and among such we may rank the labor of thought, by which the impression is converted to a conscious perception, awakening, in its turn, conceptions and ideas.

No one would seriously maintain that a piece of white paper could, by its reflected light, bring about a change in the form and composition of the brain, since an opposite effect must then necessarily be ascribed to a piece of black paper, from which no light is given forth; but the two combined, the black and white, when in the form of letters in a book, awaken the most manifold feelings, conceptions, and images; and it is by means of these, and not of light, that an influence is exercised upon the properties of the brain.

SOUND AS AN IRRITANT.

The observations which we have made regarding light, apply in every respect to sound; the vibrations of the air-wave are continued through the organs of hearing, and communicated to the auditory nerve. The motion imparted to the membrane of the typanum alters its form and composition as little as those of the molecules, which have received a like motion from it. As the eye wearies in a picture gallery, although it receives less light in the same period than it would in the open air, so it is also with the ear.

FALSE IDEA OF REACTION.

The false ideas conveyed by a mere verbal term, give occasion to constant misconception. This is the case with the word reaction, which merely means an opposing agency, but is used in physiology in a very different sense. We say that the glands react upon an irritant, if the secreting power be increased by any external cause, as is perceptible in a number of the secretions at the time of applying an irritant. One peculiarity of organic bodies is, that the increased activity of the glands does not continue, even if the irritation be kept up; although it lies in the nature of things that the secretion must cease if there is no matter present capable of affording it, and that it will be again augmented in proportion to the new supply. The action of the irritant is not an action upon the glands, but upon the cause, which equally produces the secretion, so that, in consequence of the irritation, more matter is secreted at one period than at another.

Thus, in the tail of a lizard, a metamorphosis and renewal of its molecules is continually going on, and when the tail is cut off, and the cut surfaces are separated, the governing forces act against the separation of the parts by the knife, but no counter action of vital force is exhibited upon the knife. The cut surface of the severed piece of tail is not renewed, but the one which is connected with the organism grows, not in consequence of a reaction, but owing to the continuance of the causes which effect the renewal. The body of the lizard is not integrally renewed, when nutrition is absent. If the tail grow again, the other parts of the body lose a corresponding weight and volume.

The organic body resembles other bodies in all its conditions; thus many effects which have been called forth continue, even when the causes which gave rise to them have ceased to act; others are balanced, if the active cause of the disturbance cease, because within the body itself there are forces or causes of resistance at work which uninterruptedly make themselves felt.

VERBAL EXPLANATION NO ADVANCE.

The very small amount of knowledge we have gained from that period of physiology, when it was looked upon as a mere natural philosophy, sufficiently proves that the most comprehensive description of a function of the organic body, as the process of respiration or digestion, or a condition of disease, is not sufficient to impart a knowledge of it, and that the most ingenious combinations contribute nothing to our advance, if they be not sustained by a close and accurate inquiry into facts already observed, and such as yet remain to be brought to light. The imaginative faculty alone does not justify us in losing sight of the original point of view, nor in assuming that a consecutive course of views and opinions is an advance in science, since such a mode of proceeding can only be compared to that of a man revolving in a circle, and seeking to gain the greater number of different points of view. Not that these are immaterial, for they indicate the direction in which we must apply our powers; but the mere *description* of a condition, as for instance, of a catarrh being an inflammation of the mucus membrance of the nose, must not be regarded as an explanation, or as the termination to our inquiry. A new expression for catarrh, as arising from some active injury to the cutaneous nerves, is no actual again, but a mere ideal representation.

EXERCISE OF THE IMAGINATION WITH REFERENCE TO OBSERVATION.

The right use of our senses—as in the appreciation of the distance, or height, or circumference of a body—is acquired by experience and reflection, and so also is the right conception of a natural phenomenon; and the reflection of it in all its purity, undimmed by the representations awakened during our perception of it, is the attribute of a well trained mind. The botanist recognizes at a glance the existence, and the varieties of the plants around him: the painter sees a multitude of points which the unskilled eye cannot detect even after the most fixed attention. None of the experimental sciences demand this acuteness and exercise of the imaginative faculty more strongly than physiology and pathology; and in few is it more rarely met with than in medicine. Hence arise the many contradictions in the comprehension of the simplest conditions, and the close succession of the most opposite modes of cure, and the constant appearance and speedily forgotten existenee of numerous works on the unhealthiness of certain localities, on the nature of yellow fever, cholera, and the plague—works that have often been written by men, who never saw the place they describe, or a single case of any of the diseases they profess to treat of. In order to give validity to a theoretic view of chemistry and physics, it is indispensable that its truth be guaranteed by a series of practical investigations on the part of the writer. If this be wanting, the theory, although it may be the perfectly correct expression of a truth, will meet with little or no attention. It required the keen imaginative faculty of a Berzelius to save from utter disregard such a theory as that advanced by Richter* on chemical proportions, and to recognize the innate truth and existence of a common law of combinations amid a mass of false facts; among which, that single one, which forms the starting point for the table of equivalents—the nonexisting carbonate of alumina —was sufficient to destroy all faith in the others.

ERROR ORIGINATES IN FALSE OBSERVATIONS AND COMBINATIONS.

Viewed with reference to natural inquiry, every erroneous mode of investigation depends upon the want of just observations, and the false conceptions we deduce from them; and is further based upon the error of considering the simultaneous occurrence, and concurrence of two phenomena as the proof of the existence of a connection between them. In nature numerous phenomena occur, of which *one* may be inappreciable, if another given one fail, while again innumerable other phenomena may occur together, or simultaneously, without standing in any mutual relation to each other. The assumption of an erroneous connection of this kind, originates in all cases in a false mode of investigation; and thus the combination of two phenomena, only similar in some one particular relation, is always the result of incorrect observation.

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* Richter's work entitled. "*Anfangsgründe der Stochyometrie, oder Messkunst chymischer Elemente.*" (Elements of Stochyometry, or the Mathematics of the Chemical Elements,) was published in 1792. Its object was a rigid analysis of the different salts, founded on the fact that when two salts decompose each other, the salts newly formed are neutral as well as those which have been decomposed. He endeavored to determine the capacity of saturation of each acid and base, and to attach numbers to each, indicating the weights which mutually saturate each other.

OBSERVATION.

To see and perceive by the senses is a condition of observation, but sight and perception do not characterize observation.

Observation is not limited to seeing the thing itself, but likewise the parts of which it is composed; thus a good observer must perceive and seek to become conscious of the mutual connection existing between the several parts among themselves, and considered with reference to the whole.

EXAMPLES OF ERRONEOUS OBSERVATIONS—THE SUPPOSED INFLUENCE OF THE MOON UPON THE FORMATION OF DEW.

One of the most familiar illustrations of erroneous observation, is the influence ascribed to the moon in reference to the cold felt in moonlight nights, and to the formation of dew and hoar frost, while the moon in these cases is a mere spectator of their formation.

In a work, in other respects very good, published at Dresden last year, on the influence of the moon upon earth, the following passage occurs:

THE INFLUENCE OF THE ATMOSPHERE UPON EVAPORATION.

"In the absence of an atmosphere we cannot conceive the existence of water, or any similiar fluid in a liquid form. If our globe were suddenly deprived of air, its rivers and seas must evaporate, and the whole earth would in a short time dry up, as we see exemplified on a small scale by experiments under the air pump." Here, as we see, a connection between the atmosphere and evaporation is presupposed, which does not exist in nature. Without an atmosphere it is true no clouds would be formed, liquid water would not be converted into vesicles of vapor, and aqueous vapor would not rise to so great a height; but the atmosphere has no effect upon evaporation, and an equal quantity of aqueous vapor is produced under the receiver of the air pump, whether or not the air be exhausted."

DILUTION OF THE OXYGEN OF THE ATMOSPHERE BY NITROGEN.

We find in many physiological works the view advanced, that the nitrogen of the atmosphere contributes to the dilution of the oxygen, and the modification of its action upon the organism; while in fact the quantity of oxygen in a given space would not in any respect be changed, were we to assume that the nitrogen had suddenly been removed from the earth. Two gases varying in their nature exercise a certain pressure upon the human body and the surface, with which it is brought in contact; but the particles of the *one* gas do not compress those of the *other.* If we take two bottles, one filled with nitrogen, and the other exhausted, and bring them in contact by a glass tube, the nitrogen will distribute itself through both vials; if again both bottles are of equal volume, both will contain an equal amount of gas, and the same thing happens when one vial instead of being exhausted is filled with oxygen at an equal pressure; the nitrogen will distribute itself in the bottle as if no oxygen were present—the action of oxygen similar to that of nitrogen.

THE POWER OF THE SUN IN ATTRACTING WATER.

The fact of the impracticability of working some mines in the height of summer, owing to the veins or shafts being filled with water, has led naturalists to ascribe to the beams of the sun a power of attracting water, which, according to them is to be naturally explained by the action of the sun in drying up the soil, whence hollow spaces are formed which are again filled from below by capillary action. We know that a connection between the sun and the water takes place within the mine, but this simply depends upon the drying up of the brooks in summer; as the pumps which are destined to draw away daily an equal quantity of water, are impeded in their action by the stoppage of supply from these sources.

An analogous explanation may be given of the connection between the immoderate use of spirituous liquors and self-combustion, since it is most probable that none but drunkards would be likely to fall into the fire, and be thus consumed.

THE IDEA OF BOERHAVE ON THE ORIGIN OF ALKALIS IN PLANTS.

The false ideas concerning vital and material forces, which at this moment separate by an unfathomable abyss, the department of physiology from that of chemistry, arise entirely from the absence of *true*, and the presence of *erroneous* views; thus the ideas entertained in the eighteenth century of the occurrence of alkalies in plants, may be placed side by side with those entertained in pathology at the present day concerning the growth of a crystal, and the nutrition of an organic being. According to Boerhave the alkali belonged neither to the sap nor to the individual parts of the plant, but was a product of the process of combustion; and he represented to his hearers that decayed wood yielded no alkali which was as little a constituent of the plant as the glass, which many plants give on incineration.

FALSE COMPARISON BETWEEN THE COHESIVE FORCE OF CRYSTALLIZATION AND THE ORGANIC FORCE.

"Crystals like cells," so says Henle in his (Rationelle Pathologie,)* "are restricted even under the most favorable conditions to a final limit of growth, although the former are less narrowly circumscribed than the latter. Crystals associate themselves together like cells in aggregate bodies, reminding us by their arborescent arrangement of the elementary parts in the higher plants. Material and vital bodies offer a certain measurable degree of resistance to external influences, but accommodate themselves to circumstances, even changing their forms occasionally. The most remarkable point of similarity between crystals and organized beings, is shown after injury from external influences. Crystals like organic bodies have the power of regenerating lost parts more or less fully. In both, the force which formed the body continues at work, independently of the matter which it has survived, or replaced. Thus if a crystal from which the angles have been cut off be laid in a fluid whence it may draw a substance analogous in composition to itself, it will increase generally, but more especially in the direction of the part where it was injured, so that the regular figure is first restored, just as an injured animal will, before all else, regenerate any lost part as far as typical laws permit regeneration in his individual case."

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* Part i. p. 101.

However true it may be that augmentation in the mass of an organic body be occasioned by the force of attraction, there is no resemblance externally between the growth of a crystal and the formation of an organism. The form of the membrane is not affected by the physical form of the atom, as it is in crystals, for instance, in a crystal of alum, consisting of an aggregate of particles of alum, where each individual crystal has a form precisely similar to that of the aggregate body The cell is a whole within itself, and not an aggregate of smaller cells.

EXPLANATION.

Crystals have not, like cells, a limit of growth: the increase of size in the crystal is not occasioned by a cause acting from within in an outward direction, as in living organisms, but by the force of attraction upon the surface. This force is active at every point of the outer surface, while the molecules below take no part in the growth, and may even be removed without depriving the superficies of their capacity to increase. The new planes which are formed on truncating the angles of a crystal, exercise no stronger attraction on the molecules of the surrounding medium, than do the other planes; and they do not in any special manner perfect themselves.

By cutting off an angle from an octohedron we obtain a cubic superficies of the crystal, bounded by four converging octohedric planes; in a crystalizing fluid the body increases in three dimensions; the four superficies become longer and broader, and, in consequence of their elongation and convergency, the angle is restored, even when the cubic superficies has been incrusted. But when one angle is struck off a cubic crystal of alum, and the crystal be thus truncated, it does not increase, in the mother liquid, in a greater degree towards the truncated angle than towards any of the other sides; the original cube-like figure is not restored, because the force of attraction of one individual portion of a cubic plane is not greater than the attractive force of an equally large portion of any one of the six superficies of the outer surface.

A crystal which grows in a saturated solution, always increases on one side *especially*, that is, on the surface directed towards the bottom of the vessel, owing to this plane being always in contact with those particles of the saline solution, which have the greatest specific weight, and are most copiously charged with the crystallizing matter. There are also cases in which, in consequence of the difference of temperature of the upper surface and the bottom of the vessel, the crystal increases most in a downward direction, while the upper parts lose their form.

COMPARISON OF THE PARASITE THEORY WITH THE CHEMICAL THEORY OF CONTAGION, MIASMA, AND PUTREFACTION.

The source of the most frequent errors in judging of a condition of disease, originates in regarding things that frequently occur simultaneously, as necessarily exercising a mutual influence on each other; looking upon the one as the cause of the other. For the comprehension of diseased conditions and the choice of means to remove them, there is no view which is more deficient in a scientific basis, than that of identifying miasma and contagion with living organisms, as parasites, fungi, and infusoria; and regarding them as being developed and increased in the healthy body, where they thus induce a condition which may terminate in death.

A glance at the principles of the parasite and chemical theories, will suffice to show the respective merits of each.

But if, in the following remarks, I attempt to lay before my readers, by means of a series of facts, certain processes of the living organism, together with their relation to certain phenomena, observed in inanimate nature, I do it much less with the desire of advancing any new views regarding the nature and substance of contagion and miasma, or bringing forward the question of fermentation and putrefaction, than of drawing the attention of naturalists to a cause which, although hitherto ill observed, is one that prevails generally, wherever a change occurs in the form and property of matter, or wherever combination and decomposition are going on. And if proof be adduced, that this cause exercises a decided and referable influence upon the indication and direction of the forces of cohesion and affinity, its undeniable share in the actions of vital force will be the less questioned, since vital force belongs to the same category as chemical forces, as far as the former manifests its activity only by direct contact, or at immeasurably small distances.

INFLUENCE OF MECHANICAL MOTION ON CRYSTALLIZATION.

Every one knows that water freezes at all temperatures below 32° F., and that during the act of freezing the temperature remains at 32° F.; nevertheless, water may be cooled as low as 5° F., without becoming solid, if the fluid be in a state of perfect rest. The least disturbance is sufficient to effect congelation.

INFLUENCE OF MECHANICAL MOTION ON CRYSTALLIZING SOLUTIONS OF SALTS.

The same conditions affect a number of solutions of salts, dissolved by heat; if cooled in a state of perfect rest they do not precipitate any salts, and no separation occurs between the water and the dissolved salt, while the least disturbance—a particle of dust or a grain of salt thrown into the water—will induce the molecules thus disturbed to crystallize, and when once crystallization has begun, it is continued throughout the whole mass.

INFLUENCE OF MECHANICAL MOTION ON SULPHURET OF MERCURY, IODIDE OF MERCURY, AND IRON.

By constant shaking and friction, the black amorphous suphuret of mercury is converted into crystalline cinnabar, while the rough iron, whose parts are irregularly deposited, becomes crystalline on being hammered. On rubbing a portion of lemon colored iodide of mercury, it passes into a new state of crystallization, and becomes scarlet.

From these facts it is shown that a mechanical motion exercises an influence upon the indication of the force which governs the condition of the body, and this motion is continued to its smallest molecules; for the formation of crystals it is necessary that they should be turned towards the direction in which the force of attraction is the strongest; it is, therefore, clear that atoms can be put in motion in fluids, as well as in solid bodies, by a stroke or blow, by friction, or by some other mechanical cause. The causes do not, however, exercise a certain influence on the indication of the cohesive power alone, but also upon the chemical affinity.

INFLUENCE OF MECHANICAL MOTION ON THE INDICATION OF CHEMICAL AFFINITY.

In a weak solution of chloride of potassium, tartaric acid does not deposit any precipitate: but mere shaking, or the friction of the inner wall of the vessel with

a glass rod instantly causes a deposit of crystals of bitartrate of potash. The fulminates of silver and mercury explode with the greatest violence on the application of a blow, or of friction; the same is the case with Berthollet's fulminate of silver, with picrate of lead, and many other compounds. It is clear that in these cases the blow or friction, or more correctly, the motion, is imparted to the atoms of these combinations; that the direction of their attraction is thereby changed, and that, consequently, new products are formed. Fulminate of silver contains cyanic acid. By the blow or friction, a new mode of arrangement is brought about: a part of the carbon developes itself, and combines with the oxygen, forming carbonic acid; nitrogen developes itself with the carbonic acid, and explosion is the result of the sudden transition to the gaseous form. The colorless fluid styrole becomes solid and hard through the influence of a purely mechanical motion.—(*Sullivan.*)

HEAT SIMILAR TO THE ACTION OF A MECHANICAL FORCE.

A number of bodies are decomposed by heat, and in these cases its action is perfectly similar to that of a mechanical force. Heat acts like a wedge driven in between the atoms. If between two atoms the resistance, which the chemical force that held them together, has opposed to the entrance of the wedge be less than the force which separated them, the atoms fall asunder, and decomposition is the result. Oxide of mercury is resolved into oxygen and the metal. Heat acts in the same manner on bodies composed of more than two elements. At a certain temperature the fulminates of silver and mercury, Berthollet's fulminate, and picrate of lead explode. Heat alters the original mode of arrangement of the atoms, and, consequently, the equilibrium of their mutual attraction; under its action they are then deposited in the directions to which their attraction is the strongest. The formation of new products rests upon the establishment of a new state of equilibrium, and they suffer no further change as long as they continue exposed to the same degree of heat; but if the temperature be raised, a new disturbance occurs, and, consequently, a new state of equilibrium, and a new mode of arrangement of the elements. On being exposed to a faint red heat, acetic acid is decomposed into carbonic acid and acetone; the carbonic acid contains two-thirds of the oxygen, while the acetone contains all the hydrogen of the acetic acid; at a higher temperature the acetone is decomposed into a compound of carbon which contains oxygen, and into an oleaginous hydro-carburet. Exposed to a temperature of 392° F., the styrole becomes solid and hard, loses its fluid character, and passes into a form resembling the most beautiful crystal glass.

INFLUENCE OF THE CONDITION OF CHEMICAL ACTIVITY.

It has been observed that platinum does not decompose nitric acid, and that it is neither oxidized or dissolved by this acid. A compound of platinum and silver dissolves, however, easily in nitric acid.

INFLUENCE OF THE CONDITION OF CHEMICAL ACTIVITY UPON THE CAPACITY OF BODIES TO ENTER INTO COMBINATIONS.

Metallic copper does not decompose water, when boiled with sulphuric acid; certain compounds of zinc, copper, and nickel dissolve, however, easily in sulphuric acid, with a development of hydrogen. In certain relations, compounds of these three metals will not dissolve in sulphuric acid, but if a trace of nitric acid be present, oxidation begins, which is then continued without further co-operation of the nitric acid. The solution of the platinum and copper follows in both cases against the electrical laws; heat or other causes, which might increase the affinity, have no share in the process.

INFLUENCE OF THE SAME CONDITION UPON THE CAPACITY OF BODIES TO SUFFER DECOMPOSITION.

If, further, binoxide of hydrogen be brought into contact with hyper-oxide of lead or hyper-oxide of silver, the decomposition of the former is accelerated, as by many solid bodies, and it is resolved, with effervescence, into oxygen and water; but the molecules of both metallic oxides undergo a like decomposition when in contact with the decomposing parts of the binoxide of hydrogen; oxide silver is resolved into oxygen and the metal, hyper-oxide of lead into oxygen and oxide of lead. Both oxides behave as if they had been exposed to a faint red heat.

It follows, from these appearances, that the condition of the combination or decomposition of a body, or of its change of place or motion, may exercise an influence upon the molecules of many other combinations brought in contact with it; they pass into the same condition; their elements are in a like manner separated, and they thus gain the power, which they did not possess in themselves, of entering into a combination.

The decomposition of the second body naturally proves that the resistance of the force, which strives to hold the atoms together in their original mode of arrangement, must be less than the force of that activity which affects it.

INFLUENCE OF A SIMILAR CONDITION UPON ORGANIC SUBSTANCES.

The property possessed by any substance in combination or decomposition, to call forth in other bodies of similar or dissimilar nature in contact with it, a condition of form and character like its own, belongs, in a much higher degree, to organic bodies than to inorganic substances.

DECAYED WOOD.

Decayed wood brought in contact with that which is sound, changes gradually the sound body, under similar conditions, to a state of decomposition.

RELATION OF UREA AND HIPPURIC ACID IN URINE.

In fresh urine, if there is a complete exclusion of oxygen, no change of the urea, or of the hippuric acid contained in it occur; or exposure to the air, another substance, occurring in urine in consequence of the oxygen being taken up, suffers a change in form and properties, which is communicated to the urea and the hippuric acid. Urea is decomposed into carbonic acid and ammonia, and in the place of the hippuric acid which disappears, benzoic acid is found.

INFLUENCE OF THE PUTREFACTION OF WOOD ON THE OXIDATION OF HYDROGEN.

Decayed wood takes up oxygen from the air, and gives out an equal volume of carbonic acid. If hydrogen be added to the air, it becomes oxidized with the wood, and acquires the property of combining, at the ordinary temperature, with the oxygen.

Under similar circumstances the vapour of alcohol absorbs oxygen, and becomes changed into acetic acid.

THE FIBRIN OF THE BLOOD AND YEAST ACT SIMILARLY TOWARDS BINOXIDE OF HYDROGEN.

Fresh fibrin stands in the same relation to air as damp wood, passing equally into a state of decomposition; if, in this condition, it be decomposed by binoxide of hydrogen, the latter is immediately resolved into oxygen and hydrogen; but if the fibrin be heated to boiling, this accelerating action ceases entirely. Yeast behaves in a like manner, occasioning an immediate decomposition of the constituents of the binoxide of hydrogen; but if it be previously heated to boiling, the action ceases.—(*Schlossberger.*)

RELATION OF COMBINED ORGANIC ATOMS AMONGST THEMSELVES.

These properties are in the highest degree appreciable in complex organic atoms. The larger the number of individual elements and atoms, which have associated themselves into a group of atoms of definite properties, and the more various the directions of their attractions, the smaller in the same relation must the force be which attracts together every two or three of the minutest molecules of the group; they offer a slight resistance to the causes—whether heat or chemical affinities—which effect a change in their form and properties; and are as easily changed and decomposed as other substances of simple combination.

PUTREFACTION.

The constituents of plants and animals into which sulphur and oxygen enter are formed of compound organic atoms; from the moment they are separated from the body, and come in contact with the air, they pass into a state of decomposition, which, once begun, continues even after the air is excluded. The colorless sections of a potato, turnip, or apple, soon become discolored and brown on exposure to the air.

In all these substances, the presence of a certain quantity of water, by which the minutest parts receive mobility, is a necessary requirement, in order that on a transient contact with the air a change of form and properties, and a breaking up into new products may be called forth; both of which continue until not a particle of the original body remains. This process has been familiarly designated by the term putrefaction.

AFFINITY NOT THE CAUSE OF PUTREFACTION.

Experience teaches us further, that a number of substances brought in contact with these putrefying sulphurous and oxygenous matters, when in the act of putrefaction, in like manner change their properties; in the act of decomposing, their elements, group themselves into new products, in the composition of which there are, in most cases, none of the elements of the putrefying substances taken up. From all these phenomena it is clear that the decomposition of the second body is not effected in consequence of an indication of affinity, since the idea of affinity is inseparable from the idea of combination.

DECOMPOSITION OF AMYGDALIN AND ASPARAGIN BY PUTREFYING SUBSTANCES.

In contact with the nitrogenous constitutent of germinating barley (diastase) asparagin is resolved into succinic acid and ammonia; amygdalin resolves itself with the nitrogenous constituent of sweet almonds (emulsine) into prussic acid, oil of bitter almonds and sugar; salicin into saligenin and sugar.

THE CONVERSION OF STARCH INTO SUGAR.

Potatoes and the flour of the cereal grasses contain no sugar. The mere contact with water is sufficient, in consequence of the change that is thence effected in the sulphurous and nitrogenous constitutents, to bring about a conversion of the starch into sugar.

THE SAME EFFECT PRODUCED BY ANIMAL MEMBRANE.

Animal membrane, when moistened with water, causes sugar of milk and grape sugar to pass into lactic acid; a similar property is possessed by the gluten of the cereal grasses, by animal casein, and by diastase.

FERMENTATION AND ITS PROPERTIES.

The property of an organic body to pass into the same state of putrefying decomposition as the body with which it is brought in contact, is termed the process of fermentation.

DIFFERENT DEGREES OF PUTREFACTION, AND THEIR INFLUENCE UPON FERMENTATION.

If it be true that the change of form and property in the fermenting body be dependent upon those which are effected in the putrefying body, or in the agent of fermentation: if the new order of deposition of the atoms of the one body, be influenced by the direction in which the parts of the other arrange themselves; if finally, the fermenting body behave as if it were a part or constituent of the agent of fermentation, it is clear that the mode of separation in the one must change with that of the other body; the fermenting body must yield other products if the disunion, or the chemical condition of motion change the agent of fermentation. Innumerable experiments testify to the correctness of these conclusions.

MILK OF ALMONDS AND SUGAR.

When the milk of almonds, which in its fresh state exercises no influence upon sugar, is left for a short period of time, it ceases to act upon amygdalin: and if in this condition sugar be added, the latter begins to ferment, and separates into alcohol and carbonic acid. If the almond milk be left still longer, it converts the sugar into lactic acid. A similar property is possessed by diastase, which, when fresh, converts starch into sugar; but after a period of eight days, it loses this action, and gives to fermentation.

CASEIN AND SUGAR.

In the first period of its putrefaction the casein of milk converts the sugar of milk and the grape sugar into lactic acid; at a higher temperature the sugar of grapes passes into alcohol and carbonic acid; and if the formation of free acids be hindered by the addition of an alkaline base, the casein in the last stage of its metamorphosis, occasions a decomposition of the saccharine atoms into carbonic acid, butryic acid and hydrogen.

ANIMAL MEMBRANE AND SUGAR.

Animal membrane behaves in the same manner. At first it effects a change of the starch into sugar, then of the sugar into lactic acid, and subsequently of the sugar into carbonic acid and alcohol.

THE INFLUENCE OF A HIGHER TEMPERATURE UPON FERMENTATION.

The same sugar of beet root, which ferments at an ordinary temperature, and is decomposed into alcohol and carbonic acid, yields, on raising the temperature of the juice without the addition of any foreign substance, mannite, lactic acid, gum, carbonic acid and hydrogen.

FOUSEL OIL FROM SUGAR.

The same sugar yields, on changing again the conditions of its fermentation, butyric acid; it is decomposed, in the fermenting molasses of beet-root sugar into water, carbonic acid and hydrated oxide of amyle (fousel oil.)

SEPARATION OF THE SUGAR, SIMILAR TO THAT OF ACETIC ACID OCCASIONED BY THE ACTION OF HEAT.

Milk sugar and sugar of grapes contain the same elements as lactic acid, and combined in the same relative proportions.

The products which appear on the fermentation of sugar of grapes contain precisely the same elements as an atom of sugar. Its decomposition is a simple separation, or transposition of its atoms, as is seen in acetic acid on the application of a higher degree of temperature. The carbonic acid contains two-thirds of the oxygen: the alcohol all the hydrogen of the atom of sugar.

THE PROPERTY OF CAUSING FERMENTATION IS COMMON TO ALL COMPOUND ORGANIC ATOMS.

If we take into consideration that the capacity of producing putrefaction or fermentation is common to bodies of the most various forms of composition; that blood, meat, cheese, membranes, cells, saliva, diastase, milk of almonds, &c., gain this property as soon as, by the chemical action of oxygen, a disturbance of the state of equilibrium has been excited in the attraction of their elements, it would seem that all doubt of the true cause, by which these phenomena are brought about, must vanish.

CAUSES OF THE CHANGE OF FORM AND PROPERTY OF MATTER.

A change of place or position in the most minute particles of a number of compound substances, and their decomposition, or conversion into new products may be called forth by chemical action, by heat, or electricity; and it may also be occasioned by a transference of some condition of motion, or by contact with a body, the particles of which are undergoing a change of place.

CONTINUANCE OF THE DECOMPOSITION.

If, from any external cause—by contact with oxygen, &c.—the condition of equilibrum in the attractive force of the elements of one of these compound atoms be disturbed, the result is the establishment of a new condition of equilibrium. The motion imparted to the first molecule is transferred to the second, the third, &c., of the parts of similar nature, extending even to all dissimilar particles, and to all other substances, if the force which held together their elements in their original form and character be less than that acting upon them with an opposite tendency. Want of power to maintain an original condition is want of power of resistance. Every body which is capable of offering this degree of resistance, hinders putrefaction and fermentation in most cases by entering into a chemical combination with the body susceptible of either of these conditions; and the power of maintaining the original mode of arrangement is strengthened by every new accession of the force of attraction. To the force which maintains the condition of the first body, is added a second attraction which must be overcome before the elements of the first can change their locality or size.

ANTISEPTIC SUBSTANCES.

Amongst the substances which counteract putrefaction and fermentation we must mention before others, sulphurous and arsenious acids; further, many mineral acids, metallic salts, empyreumatic substances, volatile oils, alcohol, and common salt.

These substances exercise a very unequal influence upon putrid matter. Alcohol and common salt in certain quantities arrest putrefaction, and consequently the process of fermentation, by removing from the putrid body a certain quantity of water, which is a necessary requirement for this change, Sulphurous acid, which is capable of entering into combination with all organic matters generally, and therefore, with all bodies susceptible of putrefaction, hinders this process on the same principles.

RELATION OF ARSENIOUS ACID TO MEMBRANES.

Arsenious acid does not exert the smallest influence upon the fermentation of sugar in the juices of plants, or upon the action of yeast on sugar:—(*Schlossberger.*) Neither does it affect the putrefaction of the blood, but its action on membranes and the membranous structures is unquestionable. Whilst a bladder, or a bit of membrane covered with water is thoroughly decomposed and liquefied, giving off, in the course of six weeks or less, a most offensive stench, another piece of membrane or bladder likewise in contact with water will remain unchanged and without smell, if arsenious acid have been added to the fluid; the explanation of this difference is, that the gelatinous tissue enters into combination with the arsenious acid in the same manner as skin combines with tannic acid.

By means of a knowledge of the causes of the origin and extension of putrefaction in organic atoms, we are able to give a simple reply to the question of the nature of many forms of contagion and miasma, as the following remarks will show.

EXTENSION OF THE PROCESSES OF PUTREFACTION AND FERMENTATION IN THE LIVING ANIMAL BODY.

It still remains a question with many, whether there are facts to prove that the condition of decomposition or putrefaction of a substance be propagated to parts or constituents of the living body, and whether by contact with the putrefying substance, a condition will be induced in the parts of the human body, similar to that at work in the molecules of the putrid matter. We think there can be no hesitation in answering this inquiry in the affirmative.

FACTS.

It is a fact that the dead body often passes into such a state of decomposition while in the anatomical theatre that the blood of the living body is affected by it; the slightest puncture with a knife that has been used in dissection induces a dangerous or even fatal termination. The facts observed by Magendie that vomiting, lassitude, and even, after a prolonged period, death has been induced, by applying blood that is in a state of putrefaction, cerebral substance, bile, and putrefying pus to fresh wounds, have never yet been contradicted.

It is a fact that the use of many articles of food, as ham, sausages, &c., in certain stages of their decomposition, induce the most dangerous conditions of disease in the healthy body, and not unfrequently are the cause of death.

WHAT IS TO BE UNDERSTOOD BY THE TERM "PRODUCTS OF DISEASE."

These facts prove that an animal substance in the act of decomposition may induce a process of disease in the bodies of healthy individuals, and that this condition can be transferred to their organs and constituent parts. But as the products of disease can be only understood to mean parts and conditions of the living body in a condition of change in their form and properties, it is clear that as long as this condition remains imperfect, disease may be transferred to a second, or third individual, &c.

ANTISEPTIC SUBSTANCES RETARD THE EXTENSION OF CONTAGION AND MIASMA.

If now we take into consideration, further, that all those substances or causes which destroy the propagating tendency of contagion and miasma, are at the same time requirements for the removal of all processes of putrefaction and fermentation—if daily experience show that, empyreumatic substances, as pyroligneous acid for instance, which most strongly counteract decomposition, are the means of changing entirely the process of disease in wounds suppurating unhealthily, and if further free or combined ammonia (the almost invariable product of putrefactive processes) be found during many contagious diseases, as for instance, typhus in the surrounding atmosphere, and in the urine and fæces; it surely then seems impossible to entertain a doubt concerning the cause of the origin and further propagation of a number of contagious diseases.

PUTREFACTION PROCESSES AS CAUSES OF CONTAGIOUS DISEASES.

General experience has at length shown us that "the origin of epidemic diseases can often be traced to the putrefaction of a number of animal and vegetable substances; that miasmatic diseases become epidemic where there is constant decomposition of organic matter in marshy, damp districts. And that they also develope themselves epidemically under similar circumstances after inundations; besides, in other places where a large number of people are assembled together with little change of air—as in ships, prisons, and besieged places, &c.;[*] further on, at page 27, the same author observes that "we can never prognosticate the origin of epidemic disease with more certainty, than when a marshy flat has been dried up by continued heat, or when excessive heat follows extensive inundation."

CONCLUSIONS.

Here our deduction is fully justified according to the rule of natural inquiry, that in all cases where a process of putrefaction has preceded the first indications of disease, or where disease can be communicated by solid, fluid, or gaseous products, and where no more immediate cause can be adduced, the substances or matter in the act of decomposition must be looked upon as the most probable cause of disease.

POWER OF INFECTION—IN WHAT IT CONSISTS.

The requirement for the capacity of infecting a second individual, is the presence in the body of the latter of a substance which can oppose no resistance either in itself, or through the vital energy in the organism to the causes affecting a change of form and property. If this substance were a necessary constituent of the body, disease must be transferable to all individuals; if only an accidental constituent, those persons alone would be infected in whom this substance was present in sufficient quantity, and of the characteristic nature. The termination of disease is only a destruction and removal of this matter; it is a re-establishment of the condition of equilibrium of those causes in the organism which regulate its normal functions, and which had been temporarily suspended.

A CHALLENGE TO INVESTIGATION.

Practical medicine will soon decide whether this view be correct or not; and it will then be shown whether there is any actual connection between the relation of arsenious acid to animal membranes out of the body, and their action in certain fevers; and between the relation of mercurial compounds to animal substances, and their action in contagious diseases.

If this so-called chemical view do not serve as a guide and director to the physician, after a careful study of the processes of putrefaction of simple and compound bodies, and of the materials and causes by which these processes are altered, hindered, or accelerated; and if a comparison of this with other analogous processes in the human organism, be not the means of enlarging his views

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[*] Henle, Untersuchungen, p. 52.

upon disease, and raising to a more scientific basis his knowledge of the remedial agents to be employed; then, indeed, it were of no avail to endeavor to support this theory. Its simplicity has stood much in the way of its being generally received; for at the very time that every physician or physiologist does not hesitate to ascribe the most striking changes in vital processes to bad nutriment, want of fresh air, or the continuous use of salted food, &c.—while no one feels any scruple in assigning a scarcely appreciable difference of temperature as the cause of inflammation, fever, and death—one of the most important causes of a change of form and properties is disregarded, as exercising no influence upon the organic vital process.

Here is a theory strengthened by a firmly linked chain of numerous and most evident facts, to which a critical investigation is denied, although there is nothing that can be advanced against it save its comprehensibility. But it is precisely on this latter character that the difference rests, which is observed in the result of various methods of physical investigation. Although every pathologist and physiologist is fully convinced that no organic process can be explained without the co-operation of chemical and physical forces, every theory which has hitherto been based upon such causes has been invariably doubted and rejected.

If we compare the so-called chemical theory with the principles of the parasite theory, we cannot comprehend how intellectual men, and the most practised observers, can defend and lend their sanction to views which the experience of each succeeding day must refute.

THE PARASITE THEORY.

The principles of the parasite theory may be referred to two facts, viz., to the propagation of the itch, and to a disease appearing in silk worms called *muscardine.*

THE ITCH.

The itch is an inflammation of the skin, occasioned by the irritation of a kind of mite (acarus scabiei, sarcoptes humanus,[*]) which lives upon the skin, or, more correctly speaking, burrows within it. For the communication of the itch continuous vicinity is necessary, and that especially at night, as the itch mite is a nocturnal depredator. The fact of the itch mite being the vehicle of the contagious character of the itch, is proved by the following facts: inoculation with the pus of itch pustules does not engender the itch, any more than the application of the crusts of scabious pustules upon the arm. Secondly, the disease is healed by rubbing off the mites with brick dust; and it can only be propagated by the impregnated female animalcule. The itch may continue until it induces general permanent disease, which in these cases becomes established, and cannot be spontaneously cured.

THE ITCH A CONTAGIOUS DISEASE PROPAGATED BY AN ANIMAL.

Contagion of the itch is, according to this theory, an animal with a mandibular apparatus, which lays eggs; we term it fixed contagion, because it cannot fly, and its eggs cannot be transported by atmospheric influence.

If it be proved that the itch may be propagated by animals, it requires neither a chemical nor any other theory to explain the communication of the disease; and it becomes evident that all conditions which are similar to the itch belong to this class, where observation shows approximating or like causes, for the communication and extension of the disease.

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[*] An excellent account of this insect, and of the other parasites infesting the human body is given in Vogel's Pathological Anatomy. See Dr. Day's translation, p. 419.

CONTAGIOUS DISEASES NOT COMMUNICATED BY ANIMALCULES.

If now it be asked, what results have been obtained from investigation into these and other similar causes of infectious diseases, we may answer that in the contagion of small pox, the plague, syphilis, scarlatina, measles, typhus, yellow fever, dysentery, hydrophobia, &c., the most attentive observations have not been able to trace any animalcules or organic entities to which the means of propagating the disease could be ascribed.

PARASITES IN BODIES OF THE HIGHER CLASSES OF ANIMALS.

We have already observed, that there are a number of insects which can alone be developed and propagated in the body or under the skin of the higher animals, and that they may, in many cases, induce disease, and even death; and it will, therefore, be perfectly clear that the itch mite belongs to this class of diseases, since the size of the animalcule can make no difference in the explanation.

There are, accordingly diseases occasioned by animalcules, parasites, which develope themselves in the bodies of other animals, and thrive at the cost of some of their constituent parts; and they cannot be mistaken for other diseases, where such causes do not prevail, whatever resemblances there may be in external indications. It is possible that further observations may attest the fact, that some or other of the contagious diseases belong to the class dependent upon parasites; until, however, such a fact be established, we must, according to the rules of natural investigation, avoid assuming it. It is the province of scientific inquiry to discover the especial causes by which they have been induced, the simple question concerning which will lead the way to an explanation of the subject.

That infection in contagious diseases is dependent upon an organic being, and that the itch must be regarded as a type of contagious diseases, were facts which it was endeavored to ground upon the deduction of like effects springing from like causes.* A similar mode of reasoning has, for centuries, impeded the advance of the natural sciences, and even continues at the present day to lead to many errors.

The pure miasmatic diseases, and their so-called miasma, have not as yet been laid open to investigation in reference to their origin and the manner of their extension, and on that account no explanation has hitherto been attempted, either by a chemical or parasite theory. The parasite theory has designated *muscardine* as the type of those miasmatic contagious diseases which arise from matter derived either from the air or from the diseased body.

MUSCARDINE.

Muscardine is a disease of the silk worm, occasioned by a fungus. The germ of the fungus, when introduced into the body of the worm, grows in eating its way into the interior, and after the death of the animal it penetrates the skin, when the surface soon appears covered with a forest of fungi, which by degrees dry up, and are converted into dust: this is raised and scattered in the air by the slightest motion of the body on which the fungus grows. Good nutrition, and perfect health and strength increase the capacity for infection; and thus, in a colony of silk worms, the finest and largest are always the most affected by the disease.

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*Henle, Zeitschrift, 2 Bd. p. 305.

PARASITES IN ANIMALS AND PLANTS.

Similar parasites have been observed on diseased fish, in infusoria, and in hen's eggs; and it is clear that these observations confirm a series of facts regarding the animal organism which often occur in the vegetable world, proving that disease and death are frequently induced by parasites, which live exclusively upon the constituent parts of other bodies; as yet, however, no connection has been drawn between these facts and the origin and propagation of miasmatic contagious diseases; and if it be allowable to designate a fungus, or its spores, by the term contagion, it is clear—since the size of the fungus makes no difference in our mode of considering it—that some sources of contagion attain to a length of six or eight inches, this being the size of the fungus, *Sphœria Robertii*, which developes itself in the body of the New Zealand grub, and occasions its death.

FALSE VIEWS OF THE CAUSES OF PUTREFACTION ARE THE FOUNDATION OF THE PARASITE THEORY.

A view of the cause of fermentation and putrefaction, which is thoroughly false in its principles, has hitherto served as the main support of the parasite theory. Its adherents regard putrefaction as a decomposition of organic beings, by infusoria and fungi, and every putrefying body as a sort of rampart of infusoria, or a plantation of fungi; and thus, according to this view, wherever organic bodies pass into putrefaction to any extent, the whole atmosphere must be filled with the germs of contagion, and become the cause of disease.

FUNGI AND INFUSORIA DO NOT OCCASION PUTREFACTION.

It has not escaped the advocates of the parasite theory, that a close connection exists between putrefaction, contagion, and miasma; although they avoid entering upon an explanation of the mode of comprehending the connection of these phenomena, and their mutual dependence upon each other. This connection would be established, if it were proved that infusoria or fungi, induced putrefaction or fermentation; that by them and their process of digestion and respiration, sugar is resolved into equal volumes of carbonic acid gas, and vapour of alcohol; and that the following conversions are brought about, viz., urea into carbonate of ammonia; salicin into sugar and saligenin; sulphate of protoxide of iron into sulphuret of calcium; sulphate of soda into sulphuret of sodium; blue indigo into white indigo; starch into sugar; sugur into lactic acid; amygdalin into prussic acid, bitter oil of almonds, and sugar.

The following remarks will show how thoroughly untenable are these views.

OPPOSITION BETWEEN PUTREFACTION AND THE PROCESS OF LIFE.

The constituents of vegetable and animal structures have arisen under the dominion of an active cause of change in the form and properties of organisms; and this is vital force, which decides the direction of attraction, and opposes the force of cohesion, heat, and electricity, destroying the influence of every cause that hinders the association of atoms in combinations of a higher order without the organism. In compositions of such various nature as the organic atoms, these other forces occasion a change of form and condition, when the vital force after death no longer opposes their action. The same leaf, or the same grape which possessed the capacity of giving off pure oxygen to the atmosphere, submits to the chemical action of the oxygen from the moment of its separation from the organism, and its being brought in contact with the air.

No organism—no portion of an animal or plant is capable, after the extinction of vital energy, of resisting the chemical action which air and humidity exercise upon it, and its elements fall back under the unlimited dominion of chemical force. Fermentation and putrefaction are the stages of its retrograde development, presenting less perfect combinations, until at length the organic atoms, in consequence of continuously acting unorganic forces, return to their simple original forms, in which they may serve for the development and nutriment of new generations.

FUNGI AND INFUSORIA ARE SUBJECTED TO PUTREFACTION, FERMENTATION AND DESTRUCTION.

Fungi and infusoria are organic beings with constituent parts of the same composite nature as those of the higher orders of vegetables and animals, and we observe the same phenomena in their bodies after death, as those which accompany the disappearance of all organisms, and find them in a state of putrefaction, fermentation, and corruption; how then is it possible to regard fungi and infusoria as the causes of these processes, when they themselves become putrid, fermented, and corrupt, leaving nothing but their inorganic skeletons?

FUNGI AND INFUSORIA ARE THE ATTENDANTS, BUT NOT THE ORIGINATORS OF THE PROCESS OF PUTREFACTION.

No one will deny that fungi and infusoria are found in a great number of putrefying and corrupting substances; but the frequency of their appearance cannot possibly be adduced as a motive for regarding them as the causes, instead of the attendants of these conditions. Fungi and infusoria are shown by nature, in reference to their nutriment and development, to be organic atoms, which have ceased to be parts or constituents of living organisms, and, in most cases, they do not appear until putrefaction be established, or is complete, and the process of corruption has begun. It cannot be doubted that all processes and their respective products are changed by their presence, for by means of their process of nutriment and respiration, they accelerate solution, limiting its baneful influence upon the surrounding parts to the shortest possible period of time.

FUNGI AND INFUSORIA HASTEN THE PROCESS OF PUTREFACTION AND CORRUPTION.

If the process of putrefaction be terminated by the return of the elements of organic beings into carbonic acid, and carbonate of ammonia, it is clear that the period necessary to effect this conversion must be most perceptibly curtailed if the putrefying agent be a plantation of infusoria, millions of whom are busily engaged in leading the constituent parts of the body into a state of decomposition by means of their respiratory and digestive processes.

BY THIS MEANS THEY BECOME THE ENEMIES OF THE PROCESS OF PUTREFATION.

It can no longer be doubted that nature has assigned to the infusoria the important part of being the enemies and opponents of all contagion and miasma; since the most incontrovertible facts have shown that the green and red infusoria are during their life, and the process of their propagation, sources of the purest oxygen.

In a similar manner fungi check putrefaction by converting to their own nutriment, the sulphurous and nitrogenous constituents of vegetables—the actual originators of corruption; and thus further, the general transition into the final products of corruption.

THE NATURE OF YEAST.

The views which the adherents of the parasite theory have formed as to the cause of putrefaction, mainly rest upon observations which have been made upon the formation of the yeast in the fermentation of wine and beer; but the investigations into the nature of the yeast are not yet closed, and it is to be presumed that the mocroscopic observations already made will be strengthened by further inquiry, and every doubt concerning its vegetable nature be thus set aside; yet even in this case the explanation regarding the separation of sugar into alcohol and carbonic acid, would admit of no other expression than that assumed by the chemical theory.

RELATION OF THE YEAST IN SOLUTIONS OF SUGAR, IN GRAPE JUICE, AND BEER WORT.

It is a perfectly well known fact that in spirituous fermentation, the elements of the sugar of grapes without any loss of weight, and those of the sugar of cane with an increase of weight, are given back in the form of carbonic acid and alcohol. We cannot here, according to our usual conceptions, speak of the conversion of the atoms of sugar to the nutritive and respiratory processes of an organic being. The weight of the yeast increases in the fermentation of the juice of the grape and beer-wort; but if we put the yeast in a solution of pure sugar and water, although the fermentation is equally produced, the yeast, in this case, instead of gaining, loses a portion of its weight; and by continuous contact of the same yeast with fresh sugar and water, it by degrees entirely loses the power of fermenting, while its weight constantly diminishes. In this case, as we see, one and the same action must be derived from two directly opposite causes, to one of which is ascribed the capacity for increase, and to the other the reverse of propagation. If we assume that the nutritive and respiratory processes of the fungi are dependant upon sulphurous and nitrogenous substances contained in their elements, and that the fermentation of sugar is an accidental phenomenon, accompanying the developing process of an organic being, then it is quite incomprehensible whence it arises that the fungi are not reproduced in a fluid, where there is present this chief requirement to their propagation, while they gain in weight as soon as sugar, the accidental attendant of this vital process, is added. If, for instance, in the juice of the grape, sugar be decomposed, and there is no free access of air, the remainder of the dissolved sulphurous and nitrogenous substances will remain dissolved in the juice for years without undergoing any change; if sugar be then added, the fermentation begins again, and yeast is again separated; when the sugar is decomposed, its separation ceases, beginning again only on a new addition of sugar; and this continues until the fluid contains an excess of sugar.

THE FORMATION OF YEAST, ALCOHOL, AND CARBONIC ACID ARE MUTUALLY DEPENDENT UPON EACH OTHER.

From these facts we evidently obtain a reciprocal relation of dependence, as required by chemical theory, between the form and properties of the sulphurous and nitrogenous body which is converted into yeast, and the new forms and properties contained in the atom of sugar; and it is clear that the condition in which the elements of the former stand during their association with the yeast, and their falling asunder into other products, is the cause of the manner in which the sugar separates. No organic beings or animals similar to fungi, have ever been observed in any other form of separation of sugar, as, for instance, in its transition into lactic acid by means of an animal membrane, or in its transition into mannit, gum, butyric acid, acetic acid, &c.; nor in any other process of putrefaction or fermentation, have organic beings been perceived, which appearing invariably in the same forms, control the nature of the products.

VIBRIONES IN THE URINE.

In many cases the presence of vibriones is detected in the urine during its state of putrefaction, while in other cases, when the urine putrefies, it is impossible to discover any organized being, and if the absence of vegetable or animal organism is certain in one single case, where fresh urine has been decomposed by the putrefying white deposit which occurs in a state of putrefaction, the fact is perfectly sufficient to remove every doubt of the true cause of the putrefaction.

FUNGI CONTAIN SUGAR.

If further we show that, in all hitherto examined fungi, analysis has yielded a quantity of sugar, which during the process of life did not pass into alcohol and carbonic acid, but that, in the same fungi, spirituous fermentation occurs immediately after their death, and from the moment when a change in the color and properties is perceived, every analogy is wanting to justify our regarding the vital process of these plants as the cause of fermentation. The action must rather be ascribed to the reverse of a vital process.[*]

CHANGE IN THE PROCESS OF PUTREFACTION IN HEATED AIR.

We may consider it as proved by the most admirable experiments, that the process of putrefaction in meat and many other animal substances assumes a totally different form, when these substances have been preserved in vessels containing heated air, and when consequently there can be no co-operation of infusoria; yet these animal substances by no means, under these circumstances, maintain their original condition; they change their color and composition, and if the water necessary to complete decomposition of the meat be present, it dissolves after a certain period into a most offensive mass.[†] We need only recall to mind the relations of fresh urine in order to perceive that in many of these animal substances a constantly renewed afflux of oxygen is a requirement for their putrefaction; that on the exclusion of oxygen, the urea does not pass into carbonate of ammonia, and that, enclosed in a vessel, these substances convert the oxygen into carbonic acid, and that with the removal of the oxygen, the whole process is arrested, or, at all events, changed.

The adherents of the parasite theory assume, that by the passing contact of sugar of grapes with the air, (without which fermentation could not begin,) the germ of the yeast plant which are present everywhere in the air, find access to a soil which affords them the necessary requirements for their fruitful development; but they do not explain the reason why the brewer is obliged to add yeast in order to turn his wort to a state of fermentation; and why these same germs, if they really were in the air, should not develope themselves in a soil so congenial to the requirements of their life and propagation. They entirely forget that the fermentation of the sugar of grapes begins with a chemical action, that a measureable quantity of oxygen is taken up from the air, that the juice becomes turbid and discolored, and the fermentation only begins after the occurrence of a precipitate; they do not consider that fermentation diminishes instead of increasing with the additional quantity of oxygen; and that under certain conditions when the matter capable of taking up oxygen has become insoluble, fermentation no longer goes on in the juice.[*]

Before all these relations have been thoroughly examined, it would be contrary to all sober inquiry to consider the vital process of an animal or plant as the cause of any process of fermentation or putrefaction; and in all cases where the presence of organic beings is not to be shown on investigation in the contagion of a miasmatic contagious disease, the hypothesis of these bodies having or taking any share in the process of disease must be rejected as altogether unsound.

TWO SIMULTANEOUSLY OCCURRING PHENOMENA ARE FREQUENTLY HELD TO BE A CAUSE, AND ITS EFFECT.

Another no less grave error in the mode of considering and deciding upon a question, is to look upon different phenomena, which are effects of one and the same cause, as mutually dependent upon each other, and regarding the description of the one phenomena as an explanation or definition of the other.

EXAMPLES.

This is the case, for instance, with the explanation which is given of fever, of crises, &c. A few examples of similarly false combinations, which daily occur in life, will best exhibit what is here alluded to.

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[*] Schlossberger, Annalen dür Pharmacie, Vol. lii. p. 117.

[†] De Saussure in his beautiful investigations observed the fact that hydrogen at a glowing heat obtained by the decomposition of aqueous vapour by means of iron, and in contact with putrifying or decayed animal substances entered into no combination with oxygen; while at the ordinary temperature, pure hydrogen was easily condensed under these circumstances. This deserves attention in an inquiry into the influence of heated air upon the process of putrefaction. Possibly the decomposition of infusoria and the germs of fungi may not be the only cause of the change in this process.

[*] Two cubic centimeters of must, three millimeters thick and thirty millim. in diameter, in contact with twenty cubic centim. of oxygen do not pass into a state of fermentation; while a similar stratum without the addition of oxygen occasions a considerable development of carbonic acid.—De Saussure in the Jahrbuch für Chemie, vol. lxiv. pp. 47—51.

A STORM REGARDED AS THE CAUSE OF UNUSUAL CHANGES IN THE STATE OF THE BAROMETER.

Nothing is more common than the opinion which ascribes to storms the effect of making the mercury fall in the barometer.

Storms are effects of a difference of temperature, or of some other causes of interrupted equilibrium of the pressure of the atmosphere. A change of the pressure of the atmosphere exhibits itself by its influence upon the rise and fall of a column of mercury, which is of equal weight with a column of air of the same diameter. The barometer and the storm do not stand in any immediate relation to each other; the storm exercises no influence upon the barometer, and the two are only combined by their mutual dependence upon one cause. And, in precisely the same manner, the fall of the barometer is connected with the occurrence of rain.

SYMPTOMS OF FEVER MUST NOT BE REGARDED AS THE CAUSES FROM WHENCE IT ARISES.

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The false ideas which many pathologists have formed to themselves of the cause of fever, belong to this class of errors regarding the *causa efficiens*, and to the confusion of ideas concerning effect and cause.

HENLE'S EXPLANATION OF FEVER.

"Although I am far from thinking," says Henle,* "that I am able to settle the controversy regarding the question of the existence of essential fevers, I yet believe I may contribute something that shall enable the contending parties first to understand themselves better, and next their opponents. It follows that as febrile symptoms are the consequences of an alteration in the central organ, so this alteration is the proximate cause of the febrile symptoms; and, as the fever depends upon these symptoms, upon the complication of the change of temperature, motion of the blood, of thirst and lassitude, this alteration must be the proximate cause of the fever—in fact the fever itself."

Setting aside that these three positions are not consecutive links of one conclusion, since each one says the same as the other two—we cannot, in accordance with the rules of natural investigation,—so long as the causal connection of the febrile symptoms and the alteration in the spinal cord be not explained—regard the febrile symptoms as any thing more than indications of the changed condition of the spinal cord. To the symptoms of fever which are externally perceptible, must be added the scientific investigation of a new indication of disease. The alteration in the central organs is a fact perceived, or to be perceived, by the senses, but not a cause.

WHAT COURSE MUST BE PURSUED IN THE INVESTIGATION OF THE CAUSE OF FEVER.

If it be assumed that this alteration is always and unalterably accompanied by febrile symptoms, the knowledge and explanation of the cause of fever must include the recognition of the connection of the three constantly recurring indications of fever—that is, the subjective feeling of indisposition, the alterations in circulation and respiration, and the changed phenomena of heat, which characterize the febrile condition, as well as the relation of their mutual dependence.

If we exclude from investigation, as inexplicable phenomena, the subjective indications, the feelings of indisposition, and of heat and cold, it still remains to trace the connection existing between the alteration of the spinal cord, the accelerated movements of the blood and the respiratory apparatus, and the altered phenomena of heat. Before we can obtain any explanation of this, we must arrive at a conception of motion, and seek the source of a moving force and heat in the animal body. If we could trace the cause of fever according to the physical method, and consider that by the co-operation of many, or let us say of two causes, a certain amount of force is engendered in the heart itself, by which the circulation of the blood is affected; then the motion will be regular or normal, if the number of the beats of the heart be equal in every minute, and when the force is thus divided over equal periods.

POINT OF VIEW OF THE INVESTIGATION.

If this same amount of force, in consequence of the disturbed relation of the two causes, which have their seat in the heart, at one time increases and at another diminishes, the pulsations of the heart will be at one time quicker, and at another slower. The force engendered is in this case not proportionate to the term of its consumption. It is clear that, on the supposition of this force being engendered in the heart, the alteration in the spinal cord can exercise no other influence upon the change in the phenomena of motion, or upon the accelerating or retarding of the heart's action, than that, in consequence of its condition, it may oppose, in some manner or other a smaller resistance to motion at one period than at another. The causes of the effects of motion do not exist in the heart alone; they are distributed in every part of the organism, in the spinal cord, as well as in every individual muscular fibre.

INQUIRY INTO THE CONNECTION OF THE SPINAL CORD WITH THE EFFECTS OF MOTION.

We may conjecture that the movement of the heart, as well as that of all other parts of the organism, the motion of the intestines, and the voluntary motions, proceed from the spinal cord, and it is evident that a change in the condition or character of this organ must be followed by a change in all the phenomena of motion. The same must happen when any part of the nerves, standing in connection with the spinal cord, and with the circulatory apparatus, &c., suffers a change of condition or properties, and this changed activity must exercise a retrograde influence upon the spinal cord and the apparatus of motion. The laws of the propagation or communication of motion, are every where the same, whatever causes may have called them forth.

The cause of motion in a mill, the rotatory motion of the stone, the bolting of the flour, &c., are not occasioned by the wheel, for that is a portion of the mill itself. It is quite certain that an irregularity in the working of the mill may be occasioned by the removal of a few of the wings of the wheel, by which the pressure of the water on these parts ceases; it may also, however, be occasioned by the breaking off of the cogs of one of the other wheels of the mill, when an irregularity of motion will be perceived not only in this wheel, but in every other part of the wheel.

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*Untersuchungen, p. 240.

REGULAR AND IRREGULAR MOTIONS.

If now the organism engender a certain amount of force in a given time, the motions will be regular, if the force proceed from the spinal cord; irregular, if one apparatus have more force than another. If subsequently the motions of the blood and respiration be accelerated, the consequence will be weakness in the limbs, or a disturbance of the digestive functions. The extra force which the heart receives in the acceleration of its action, cannot be applied to the other apparatus of motion.

After establishing the connection between the spinal cord and the effects of motion, the relations of the latter to the phenomena of animal heat must next be discussed.

RELATION OF THE PHENOMENA OF ANIMAL HEAT TO THOSE OF MOTION.

Observations show that the irregularity of the phenomena of motion is accompanied by a change in the phenomena of heat; in many cases the subjective and objective phenomena of heat rise and fall with the acceleration or retardation of the indication of motion; in other cases, again, both do not recur simultaneously in the same relations. But the phenomena of motion become more regular by the equalization of the indications of heat; and, if the former are restored to a normal state, the latter will show a proportionate degree of irregularity. If, now, it can be shown that the effect of motion (speed) does not call forth heat, (as, for instance, by friction,) it naturally follows, that heat and the phenomena of motion stand in no nearer connection with each other, than the storm with the abnormal rise and fall of the mercury in the barometer; and that, consequently, the causes which have influenced the one series of phenomena are simultaneous conditions of the other series. If the amount of evolved heat, in a given time, stand in a definite relation to the number of blood corpuscles which have passed through the capillaries in the same time, the source of heat must be sought in certain states of the blood-corpuscles, or of the blood and the capillaries.

RELATION OF THE PHENOMENA OF HEAT TO THE OXYGEN OF THE AIR.

Since it is proved, by investigation, that the condition of the blood, by which it may become a source of heat, consists in its power of taking up oxygen, and since the oxygen thus taken up in a given time stands in a definite relation to the number of inspirations within the same period, irregular effects of heat must be dependent upon the respiratory motions, the contractions of the heart, and *one external cause*—and this is, the chemical action of oxygen. As the relation of these three factors to each other is altered, the phenomena of heat must in like manner change; and when in certain parts of the organism the capacity of entering into combination with the oxygen increases from any superadded cause, more heat will be evolved in that one part than in others. When, in accordance with this, the motion of the circulation and respiration is accelerated, then will also the amount of oxygen and liberated heat be increased, which is in accordance with the beautiful law established by Vierordt. If the respiratory and circulatory motions are accelerated in unequal relations, the subjective, or objective feeling of warmth is changed. When all these relations are examined and obtained, we shall not only be able to explain the individual symptoms of the fever, and, consequently, the disease itself, but we shall then also be enabled to trace all to a final and sole cause (the cause of disease). This is the course of natural inquiry.

ERRONEOUS CONCLUSIONS DRAWN FROM BRINGING ONE CAUSE TOO PROMINENTLY FORWARD.

Erroneous combinations of conclusions of another kind are formed, when in the explanation of a natural phenomenon we only keep in view one of the many causes on which it is dependent, ascribing to it an active importance which it does not possess in and for itself, but merely receives from the presence of other causes. Thus, for instance, Schleiden bases his theory partly upon an untenable atomism, partly upon false mechanical principles, when he says, in his "Elements of Scientific Botany,"* "that fermentation and putrefaction are the effects of the communication of a motion, and that the amount of the motion will be measured by the product of the mass into the velocity. One part of diastase is said to extend its decomposing power over 1000 parts of starch (but this is an error, since, according to Guerrin Varry, one portion of diastase acting upon 60 of starch, gives only 10.3 of sugar. The relation of 16 of starch to 1 of diastase, gives only 14 of sugar.) We must, therefore, assume in an atom of diastase a velocity 1000 times greater than would be necessary for the decomposition of an equal weight of starch. Here we see that a gigantic edifice of crowded hypotheses has been erected upon the most untenable basis, in order to support a false opinion. On the other hand, the objection started as to the impossibility of one body at rest setting another in motion, borrowed from the atomic method of explanation, is likewise physically false; since gravitation, magnetism, and electrical attraction are nothing but mere examples of motion being imparted by one body at rest to another."

CORRECTION OF SCHLEIDEN'S VIEW.

As to what regards diastase, and its action upon starch, Schleiden has forgotten to take into consideration the time which is necessary to effect the conversion into sugar. The view which he contests, does not presuppose that the molecules of the diastase possess a greater velocity, but that the surrounding deposition of the molecule of starch had gone on while the motion in the diastase molecule still continued, and, consequently, before a state of equilibrium had been established in the latter. Nothing is to be understood by a communication of motion, but that the molecules of starch are kept in contact with the molecules of the diastase, as if they were parts or constituents of it. The action of the diastase in a limited time depends, therefore, upon the number of the molecules of starch that can come in contact with the molecules of the diastase in the same period of time. The number of the molecules of diastase affect the time and the process of its conversion into sugar; the action disappears with the presence of diastase, and by a double or triple quantity of diastase the time of the conversion is shortened, or a larger quantity of starch is converted in sugar.

THE MEANS BY WHICH MOTION OCCURS.

As to the view advanced regarding gravitation and electricity, as instances of the motion of one body through another at rest, we must take into consideration that a body at rest may pass into a condition of motion in two essentially different modes.

FIRST: BY THE COMMUNICATION OF A MOVING MASS.

1. By the communication of the moving mass of a body already in motion, as by means of a blow—for instance, the action of the hammer on the nail, of water on the mill wheel, or wind upon the sail.

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* Grundzüge der Wissenschaftlichen Botanik, 1845, p. 282.

SECONDLY: BY AN ATTRACTIVE OR REPULSIVE FORCE.

2. By the action of an attractive or repulsive force, which is interposed between two bodies. In this the action is always mutual, and the speed obtained inversely proportionate to the masses moved.

CHEMICAL PROCESSES, AS PHENOMENA OF MOTION, BELONG TO THE SECOND KIND.

As one must consider chemical processes as phenomena of motion, it is not to be doubted that all such processes as can be explained by the formation of new compounds belong to the second class of phenomena of motion, while the attractive force of the constituents, or their chemical affinity, calls forth the change of place and property (that is the motion) of matter. After the establishment of the combination, motion ceases, as when the falling stone has reached the ground, and the iron filings the pole of the magnet.

PUTREFACTION AND FERMENTATION BELONG TO THE FIRST ORDER OF PHENOMENA OF MOTION.

But when a body which is undergoing decomposition, that is, whose parts are in a state of change of place and of motion, converts another body into a similar condition; and if observation have shown that all other known causes, excepting one alone, must be excluded from any participation in the change, or decomposition of the second body; and if it be proved that this one cause (communication of motion, friction, a blow, &c.), have a decided share in the formation and decomposition of a number of combinations, this one cause must be regarded as the final acting one, especially, if the views gained in the theory of motion, be applicable to chemical actions. The recognition of this last, and only cause, is therefore not a mere word that has been substituted for the term "catalytic force;" but the expression of an idea, which is strictly the opposite to that of a catalytic body. From the facts advanced in (2) p. 84, the erroneous conclusion is drawn that gravitation, magnetism, &c., are examples of the motion of one body through another at rest.

THE FORCE OF GRAVITATION GIVES NO RISE IN ITSELF TO MOTION.

A clock is kept in motion by the weight, but cannot draw it up by itself, and the heat of the sun has as little share as gravitation in the action of a mill-wheel. The water which impels the mill-wheel was previously vapour—the vapour was fluid water.

The water underwent evaporation; the vapour, on the abstraction of heat, became again aqueous, and this liquid water falls by the action of gravitation, and continues to fall until, as in the clock, resistance arrests its motion.

WANT OF CORRECTNESS IN EXPRESSION, THE CAUSE OF ERRONEOUS CONCLUSIONS AND MISUNDERSTANDINGS.

Besides the erroneous conclusions and methods of investigation which are comprised in this one clause, there is yet one individual fault to be added, which prevails amongst many physiologists, and which can be explained only on the plea of carelessness. This failing is, to regard things or phenomena, that have been perceived by the senses, as representing conclusions of the mind, which brings along with it this great disadvantage, that in order to esteem a fact as true, these naturalists require to have ocular demonstration of known causes which cannot be perceived by the senses.

From this it may arise that chemists, in spite of a superabundance of the most evident facts, are frequently unable to convince physicians of the simplest truths.

EXAMPLES.

Examples of this assertion can be found in every physiological work; and I will give a few illustrations from one of the most recent treatises. Valentin says,[*] "We perceive on dividing the facial nerve, that the muscles of the face on the corresponding side are paralysed as far as the will is concerned. We thence justly conclude that the effects of our will are communicated by means of the facial nerve to the muscles of expression.

"We find, after injury of the trunk, or the branch of the fifth pair of nerves supplying the eye, that secondary inflammation, suppuration, and even further, destruction of the globe of the eye, are occasioned; and conclude, therefore, that the integrity of the above-named nerves is necessary to the normal condition of the eye."

Further on, at page 3, we find as follows: "I know that the walls of the arteries are elastic, and I may, therefore, at once conclude that they distend to a certain extent as soon as they have been filled with blood; and that on the yielding of the pressure they return to their original circumference;" that is to say, they are elastic.

POINT OF CONTACT BETWEEN PHYSIOLOGY AND CHEMISTRY.

I have shown in the above, how much the difference in the way of viewing things, adds to the difficulty of arriving at an understanding between physiologists and chemists; and I will now endeavor to consider more particularly the point of contact, at which physiology and chemistry ought to meet in order that they may mutually assist each other.

DEVIATION OF CHEMICAL AND MECHANICAL LAWS FROM THE LAWS WHICH GOVERN VITAL PHENOMENA.

If we endeavor to make use of illustrations derived from the knowledge of mechanical forces, in the inquiry of vital or chemical phenomena, we immediately observe that the laws which govern the former, differ in many respects from those on which the peculiarities of chemical or vital combinations are dependent.

RELATION OF THE PROPERTIES OF ELEMENTS TO THE PROPERTIES OF THEIR COMBINATIONS.

A chemical combination of two bodies, possesses properties which are entirely different from those of its several constituents. The chemical force of the new body, the power of entering into new combinations, or bringing about decomposition, is not the sum of the chemical forces of its elements. We are entirely unable, by tracing backwards, from the properties of a muscular fibre, to decide concerning those of carbon, hydrogen, nitrogen, and its other elements; and yet nothing can be more true, than that certain relations remain permanent between the properties of the elements, and those of their combinations.

Cinnabar is a metallic sulphuret, which possesses totally different properties from sulphuret of lead on sulphuret of zinc. It cannot be doubted that their difference is dependant upon the fact of mercury being combined in the first, lead in the second, and zinc in the third, with sulphur; and that the properties of the mercury, lead, and zinc, must have an entirely definite and definable share in the difference of the properties of their combinations, since the latter are evidently dependent upon the difference. We see this the most clearly in the isomorphous substances; sulphuret of lead is scarcely, in appearance, to be distinguished from seleniuret of lead, sulphate of alumina and ammonia, from sulphate of alumina and potash, selenate of soda, from sulphate of soda. The relations which exist between the chemical and physical properties of the elements have remained constant in many of these combinations; and in those, where there is a deviation in color, solubility, &c., one property, namely, physical form, remains constant. The same or a similar relation is doubtlessly attainable between the properties of all elements and their combinations, and all the efforts of chemistry have been directed to the discoveries of these constant relations. An investigation of this kind is the only way in which chemistry can attain to natural laws, and it is only by the same means that physiology, if it is to rise to the rank of a natural investigation, can gain a scientific basis.

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[*] Manual of Physiology, Brunswick, 1844.

THE CHEMICAL FORCES OF THE ELEMENTS HAVE A SHARE IN THE VITAL PROPERTIES.

We cannot, certainly, as yet, follow out any physical property by means of the laws or properties of the elements; but still there can be no question, that a knowledge of such properties is to be gained from laws, which arise when these elements have been, in a certain measure, arranged. When these elements have combined to form an animal or vegetable substance; when they have attained to physiological or vital properties; then the chemical forces, which have given them their original properties are no more destroyed or removed, than the cohesive power of the atoms of sulphur is destroyed when we melt a portion of that substance. There has only been another cause superadded—heat—which has removed the effect of the cohesive force, or the connection, rendering its action no longer perceptible. The new condition, that of fluidity, is one of equilibrium between two antagonising causes, an effect in which both have an equal share.

In vegetable and animal substances, the elements obey mechanical and chemical laws, if their action be not removed by resistances, which must be regarded as the indications of new laws, that govern the parts of the organism.

THE RELATIONS BETWEEN CHEMICAL AND VITAL EFFECTS MUST BE INVESTIGATED.

If by the connection of many causes, new laws and phenomena are brought forward, which have no resemblance with the actions of individual causes in themselves, the effects of the latter stand in an immediate relation to those of the new phenomena, and these are the relations which must be sought and investigated.

When we have gained a clear conception of these, we shall be able to decide concerning a number of unknown facts or phenomena, as in the case of isomorphous substances, without further observation.

THE RELATION OF THE WEIGHTS OF THE ELEMENTS TO CHEMICAL COMBINATIONS.

A purely scientific character has been imparted to chemistry by the knowledge of the fact, that the property of weight in all chemical combinations is constant, and that, in whatever manner the elements may be composed, the weight of the combination is equal to the sum of the weight of its elements. The knowledge of chemical proportions has led to our being able to predetermine all possible combinations of a body; but it could not explain the apparent exceptions of bodies, which, according to experience, united not in constant, but in every conceivable proportions. It is by the consideration of another property—the relation of external form to composition—that we have not only been enabled to give an explanation of these deviations, but have also gained a far clearer conception of the cause of the constant relations of combination.

THE UNIVERSALITY OF LAWS OF MUTUAL DEPENDENCE IN NATURAL PHENOMENA.

The advances made in all branches of natural investigation, in the physical sciences, as well as in physiology, rest upon the conviction that similar laws, based upon conditions in the properties of bodies reciprocally depending upon each other, may be obtained.

THE WAY TO ATTAIN TO A KNOWLEDGE OF THE RELATIONS OF DEPENDENCE.

There is no other method in natural investigation by which we can arrive at a knowledge of the relations in which the properties of bodies stand to each other, than by first seeking to learn these properties themselves, and next, the cases in which they vary. It is a law of nature, that the deviations in a property are, without exception, accompanied by entirely similar changes in another property; and it is perfectly clear, that the knowledge of the laws of these deviations, will place us in a position to decide concerning the one property, without any further observation of the other. The knowledge of the one, will lead to the explanation of the other.

A few examples will be sufficient to prove the truth of these statements.

EXAMPLES OF THE LAWS OF DEPENDENCE--PRESSURE AND THE BOILING POINT.

It is known that every fluid passes into a state of ebullition under the same circumstances, and at unvarying degrees of temperature; this is so constant, that we designate the boiling point as a characteristic property of fluids.

One of the conditions of the constant temperature at which air bubbles are formed in the interior of these fluids, is external pressure; the boiling point varies with this pressure in all fluids, according to an especial law, increasing or diminishing with the increase or diminution of the pressure. Every boiling point of temperature has a corresponding and definite pressure, and every pressure a definite temperature. It is known that an acquaintance with the law of the mutual dependence of the boiling point of the water, and the pressure of the atmosphere has led to our being able, by means of the thermometer, to decide altitudes above the level of the sea, and thus to measure one property by deviations in the other.

THE BOILING POINT.

The relation in which the boiling point of fluids stands to their properties is less known. Pyroligneous spirit, alcohol, and the fousel oil of potato spirit are three fluids, possessing very different boiling points. Pyroligneous spirit boils at 138° F., alcohol at 172° F., fousel oil at 274° F. The comparison of these three boiling points shows that the boiling point of alcohol is 34° higher than that of pyroligneous spirit ($138° + 34° = 172°$), while that of fousel oil is four times 34° higher ($138° + 4 \times 34° = 274°$). Each of these three fluids yields an acid upon oxidation under like circumstances: pyroligneous spirit gives formic acid; alcohol, acetic acid; fousel oil, valerianic acid. Of these three acids, each has its own boiling point: formic acid boils at 210° F., acetic acid at 249° F., and valerianic acid at 347° F. If we compare these three points, we find that they stand in the same relation to each other, as do the boiling points of the fluids from which these acids have been obtained. The boiling point of acetic acid is 34° higher than that of formic acid, while the boiling point of the valerianic acid is four times 34° higher.

A similar deviation in one property shows, as we have remarked, a similar deviation in another. The property to be considered here, is the composition. If we compare the composition of the six several bodies (of the three acids, and the three fluids,) from which they originate by the influence of oxygen, we find as follows: the composition of the pyroligneous spirit is designated by the formula, $C_2 H_4 O_2$; that of spirits of wine by $C_4 H_6 O_2$; that of fousel oil by $C_{10} H_{12} O_2$.

If now we designate by R, a quantity of carbon and hydrogen, which belongs to the formula C H. (like equivalents), we see immediately, that the composition of alcohol can be expressed by that of pyroligneous spirit+2 R.

$$\overset{\text{Pyroligneous spirit,}}{C_2\,H_4\,O_2+C_2\,H_2} \quad = \quad \overset{\text{Alcohol.}}{C_4\,H_6\,O_2}.$$

While the composition of fousel oil may be expressed by that of pyroligneous spirit + 8 R.

$$\overset{\text{Pyroligneous spirit.}}{C_2\,H_4\,O_2+C_8\,H_8} \quad = \quad \overset{\text{Fousel oil.}}{C_{12}\,H_{12}\,O_2}.$$

The formula of formic acid is $C_2\,H_2\,O_4$, that of acetic acid $C_4\,H_4\,O_4$, that of valerianic acid $C_{10}\,H_{10}\,O_4$. We easily perceive that the formula of the acetic acid can be expressed by that of formic acid+2 R, the formula of valerianic acid by that of formic acid + 8 R. In accordance with these experiments, a boiling point increased 34° F. corresponds with the occurrence or excess of 2 equiv. of carbon and 2 equiv. of hydrogen, or of 2 R. It may be seen that the relation between this group is constant, and that a conjecture concerning their composition may be made from the knowledge of the boiling point. The boiling point of the formate of oxyde of methyle is 96° F., that of formate of oxide of aethyle, 130° F., the difference between the two, 34°. From this it might be conjectured that the composition of the latter differs from the former about $C_2\,H_2$ or 2 R, and such is the case, The formula for formate of oxide of methyle is $C_4\,H_4\,O_4$, that of the corresponding compound of aethyle $C_6\,H_6\,O_4$, and therefore about $C_2\,H_2$ higher. But butyric acid boils at 311° F., and its boiling point is, therefore, about three times 34° higher than that of formic acid. The comparison of their formulæ shows that butyric acid may be looked upon as formic acid + 6 R. Toluidine and aniline are two organic bases, both so far different in their composition, that aniline contains $C_2\,H_2$, or 2 R more than toluidine. The comparison of their boiling points shows that the boiling point of aniline is 34° higher.

THE LAW OF THE RELATIONS OF DEPENDENCE IS DISTINCT FROM THE CAUSES BY WHICH THESE PHENOMENA ARE EFFECTED.

No one will deny, from these examples, the existence of a natural law for this group, nor can any one doubt that the qualities of a body stand in a definite relation to its composition, and that a change in a quality corresponds with a similar deviation in its quantitative relations. It must be especially noticed here, that the knowledge of this natural law is quite independent of the actual cause, or of the conditions which, taken together, effect the constant boiling point, for we are as ignorant of what relates to the boiling point, as we are concerning the conception of life.

THE BOILING POINT, THE SPECIFIC GRAVITY, AND THE COMPOSITION OF A BODY STAND IN RELATIONS OF DEPENDENCE TO EACH OTHER.

In the above examples we have only touched upon one of the relations of the quality and composition of bodies, there being as many of these relations as the body has properties. A law has been obtained for a large group of chemico organic combinations, by which, from the knowledge of the boiling point, and the composition of the body, it has been established how many pounds a cubic foot of the combination weighs, and that the property of the specific gravity, and consequently of the pressure which the body exerts on equal spaces, stand in a definite relation to two others, which are changed as it likewise is changed.

SPECIFIC HEAT AND ATOMIC WEIGHT.

A similar relation of dependence has been established in reference to the amount of heat which different bodies need in order to rise to the same temperature, and their equivalent weights. It is a well known fact, that different bodies receive a different amount of heat at the same temperature. Equal weights of sulphur, iron, and lead, heated to the boiling point of water, when brought in contact with ice, melt a certain quantity of it, but the amount of water produced under these circumstances is very different.

If the quantity of heat were equal in the three bodies, the weight of melted ice must amount to the same in all, but the unequal effect which is here observed proves the want of uniformity in the active cause. Sulphur melts six and a half times as much ice as lead, while iron melts four times as much. It is perfectly clear, that when we heat sulphur, iron, and lead at the same difference of temperature, say for example, from (60 to 400) with the same spirit lamp, we should have to consume half an ounce of spirit to heat lead, three ounces and a quarter of an ounce for the same quantity of surphur, and nearly two ounces for an equal weight of iron.

These differences in the amount of heat required to raise equal weights of different bodies to the same degree of temperature, and which are peculiar to each, are termed their *specific heats*. From the knowledge of the unequal amount of heat, which bodies of equal weights contain, at a similar degree of temperature, we obtain an invaluable rule of proportion, by which we are able to reckon the weights of sulphur, lead, and iron, which contain a like quantity of heat; thus, for instance, 16 parts of sulphur will melt as much ice as 28 parts of iron, and 104 of lead, at equal temperatures. These numbers are the same as the combining weights or the equivalent numbers. Like equivalents of these and many other bodies take up a similar amount of heat in order to raise themselves to an equal temperature, and if we consider the equivalents as the relative weights of atoms, it is clear that the amount of heat, which each atom takes up, or gives off under similar conditions, is the same for every atom, and when expressed in numbers, is inversely proportionate to the weights of the atoms.

It certainly is a singular result that the amount of ice which a body melts, should have served in many cases to define and establish the relations of weight, in which this body combines with others.

SPECIFIC HEAT AND TONE OF GASES.

It may appear still more singular to many that this property, in aeriform bodies, of taking up and giving off heat, stands in a definite relation to the tone produced by blowing gas through a pipe or flute. This is so truly the case, that a celebrated naturalist, Dulong, was able to compute by the irregularity of tone, the amount of heat which in a constant volume the gases give out on pressure, and take up on expansion. In order to obtain a clear insight into this remarkable connection, we must recall to mind, the beautiful idea of La Place, concerning the connection of the specific heat of a gas, with its power of propagating sound. It is known that Newton, and many mathematicians since his time, have in vain sought to establish a formula to guide us in the observation of the velocity of sound. The formula that was calculated, closely approximated to the result of observation, but there was always an inexplicable difference. As now propagation of sound takes place by means of the vibrations of the elastic molecules of the atmosphere, in consequence of pressure, and subsequent expansion, and as, on pressing together the air, heat is liberated, while, on the expansion of the atmosphere, heat is absorbed, La Place conjectured that this phenomenon must have an influence upon conducting the sound; and it was proved, that by making a correction for the specific heat of the air, the formula of the mathematician was free from all errors, and was an accurate expression of the velocity observed.

If now we compute the velocity of sound according to the Newtonian formula (that is, without reference to the specific heat of the air), and if we compare it with the formula of La Place, a difference will be perceived between the two in the length of space, which a sound-wave is computed to traverse in a second. This difference arises from the specific heat of the air—from the amount of heat which, on the propagation of the sound, is liberated from the molecules of air set in motion. It is clear that this difference in the velocity of propagating sound in other gases, which, with equal volumes, contain and give out on pressure, more or less heat than the air, must be greater or less than that of the atmosphere; and it is, therefore, easy to perceive how the numbers, which express these unequal velocities in the propagation of sound in different gases, afford us at the same time a standard by which to measure the unequal quantity of heat which they contain.

As now the height or depth of the tone depends upon the number of vibrations of a sound-wave in a second, that is, upon the velocity with which a motion once impressed propagates itself, and we know that in all gases the velocity of the propagation of a sound-wave is directly proportionate to the number of vibrations of the tones that are called forth thereby, we perceive how, by the unequal height of the tone which is brought out by means of a pipe from different gases (that is by ascertaining how much more one gas contains than another), we are able to find the specific heat of the gas. Acoustics owe the rank they hold at the present time to the great discovery, that musical harmony—each tone that touches the heart, attuning it to joy, or animating it to courage—is the symptom of a definite and definable number of oscillations of the molecules of the propagating medium, and a sign of all that can be determined according to the laws of undulations of this motion. A number of facts referring to tones might be drawn from the theory of undulation, while empirical truths have led to a corresponding knowledge of the properties of vibrating bodies, which were previously quite unknown.

It is asserted of a celebrated Viennese violin maker, that he was accustomed to select the wood for his violins, by making choice of those trees, which, on his striking them with a hammer, returned a certain sound, known to himself alone. This may be a mere fable; but there can be no doubt, that he knew the importance of selecting boards for the upper and lower parts of his instruments, which should make the same number of oscillations in a second, and that this property depended upon the thickness of the boards used.

ELECTRICITY AND MAGNETISM,—MAGNETISM AND HEAT,—MAGNETISM AND CHEMICAL FORCE.

If, finally, we consider that the electrical current passing through a metal wire stands in a peculiar relation to the magnetic properties which it receives; and if we remember that, by the magnetic needle the minutest differences of radiated heat may be detected, that the quantity of electricity in motion is expressible in numbers by means of the same electrical needle, and can be measured in cubic inches of hydrogen, and, by metalic weights; and that, finally, when we see how the causes or forces, from which the properties of bodies and their capacities to make an impression upon our senses stand in a relation of mutual dependence to each other, we cannot doubt that the vital properties are equally dependent with all others, upon these laws, and that the chemical and physical properties of the elements, with their form and method of arrangement, play an appreciated and appreciable part amongst the phenomena of life.

VITAL PROPERTIES ARE NO EXCEPTION TO A LAW OF NATURE.

It doubtless arises from the method they have adopted, that many physiologists and pathologists are led to look upon vital properties as in some degree exceptions to a great natural law; for how else can we explain the fact of their not regarding the number and grouping of those elements from which the parts of the organism have been composed as a physical property affording indispensable assistance towards the attainment of an insight into vital phenomena; how else can we explain their not taking into account, in the treatment of disease, the elementary composition of the means of cure, and the properties depending upon them, on which their action rests. The mere knowledge of a formula is not of course sufficient for this object, but it is necessary to the investigation of the laws of the relations in which the composition and form of nutrition, or of the secretions stand to the *nutritive* process; or the composition of remedial agents to the effects which they exercise upon the organism.

ANATOMY MOST ESSENTIAL.

It is certain that all advances of the physiology of plants and animals, from the age of Aristotle to the most recent times, have been facilitated by the progress made in the study of anatomy. As he must remain in the dark concerning distillation, who has seen nothing connected with the process but the still, the fire, and the worm, from whence the spirit flows, so will it be impossible to gain an insight into any process without a correct knowledge of the apparatus used. How much more, then, is this the case with the human organism, which is a complex apparatus, requiring a most accurate knowledge of the structure of individual parts before one can venture to form a judgment of the signification of the functions of the whole. —(*Shleiden.*)

We must not, however, forget that anatomy alone, from the days of Aristotle to Leuwenhoek's time, has thrown but a partial light upon the laws of the phenomena of life, as the knowledge of the apparatus of distillation does not instruct us alone concerning its uses; so in many processes, as in distillation, he who understands the nature of fire, the laws of the diffusion of heat, and of evaporation, the construction of the still, and the products of distillation, knows infinitely more of the process of distillation than the smith himself who made the apparatus. Each new discovery in anatomy has added acuteness, exactitude, and extent to its descriptions; unwearied investigation has almost penetrated to the inmost cell, from whence a new road of inquiry must be opened.

ANATOMY NOT ALONE SUFFICIENT.

If, however, as many think, the further advance of physiology is alone dependent upon the perfecting of our knowledge of the anatomical structure of organisms, chemistry can then in no way assist physiology, since its department is not to consider the form, but to establish the condition and relations of forms to their elements, and their methods of arrangement.

By a knowledge of the anatomical structure and relations of the body, anatomy alone is aided, and even by the most accurate investigation into the phenomena of motion in bodies, we shall never learn anything concerning the reasons and laws which govern them. An acquaintance with the mode and direction of motion can alone contribute to our knowledge.

WHAT MUST BE SUPERADDED.

If anatomical knowledge is to serve for the solution of a physiological question, something else must necessarily be added; and the first thing, surely is to investigate the matter from which this form was made, the forces and properties co-operating with those of life, and the knowledge of the origin of matter and of the changes which are experienced, before those relations can be learnt, in which all constituents of the organism, the fluid as well as the solid, stand to each other. Many physiologists deem that the important questions which chemistry has solved upon this subject, only enrich herself, although all these results take as low and subordinate a place in chemistry as those that have been acquired by the analysis of minerals and mineral waters.

CHEMISTRY ALONE IS NOT SUFFICIENT.

Another fundamental error entertained by others is, that one may attain to an explanation of vital phenomena by chemical and physical forces alone, or in combination with anatomy; it is, indeed, scarcely to be supposed that the chemist should be able merely by the knowledge of chemical forces to explain the existence in the living body of new laws and new causes, or that the physiologist, setting aside the action of chemical, or purely physical forces, should endeavor to account for every process by the aid of the laws of inorganic nature.

The latter view is the ultimate consequence of a reaction from the previously entertained views. In a period of philosophical physiology not very remote from the present day, every thing was explained by vital force. This theory was next wholly rejected, and the possibility assumed for our being able to trace all vital processes back to physical and chemical causes. "In the living body," thus wrote physiologists forty years since, "there are different laws at work from those which govern inorganic nature. All the processes of the living organism are of a peculiar character."

In the present day many physiologists, on the contrary, regard these various processes as similar in character. The evil of both these theories is, that neither then, or now, has any attempt been made to establish, or even to investigate the deviations occurring in the effects of vital force, and in the action of inorganic force, or to determine their similarity and differences.

The deductions drawn were not based upon a knowledge of the difference, or similarity of their mutual relations, but upon ignorance of these characteristics.

WHAT IS MEANT BY CHEMICAL FORCE.

Those philosophers who regard vital processes as effects of inorganic forces, entirely forget that the expression *chemical force* means nothing more than the *quantitative* character of different vital indications, and the qualities dependent upon these quantities. The false view taken of the influence of chemistry in explaining vital phenomena arises from one of two erroneous estimates of the science, either depreciating its effects unjustly, or entertaining too exaggerated an idea of its importance.

RELATIONS OF DEPENDENCE CANNOT BE ESTABLISHED BY A NUMERICAL SYSTEM.

If a definite connection exist, or be discovered between two facts, it does not fall within the province of chemistry to prove the connection, but simply to trace out and express its numerical character.

No relation can be established between two facts by means of numbers, if that relation does not exist; and hence the importance of the numerical system.

NUMBERS ARE ONLY EXPRESSIONS OF THE RELATIONS OF DEPENDENCE.

Bitter oil of almonds and benzoic acid are, considering their occurrence and properties, two totally different organic combinations.

A few years since, no mutual relation was even suspected to exist between the two; but now it is known that oil of bitter almonds becomes solid and crystalline in the air, and that the resulting body is identical in its properties and composition with benzoic acid. The relation between these two bodies is undeniable after this experiment. Observation shows, that in the transition of oil of bitter almonds into benzoic acid, oxygen is taken up from the air, and an analysis of the two firmly established the conversion numerically, and thus explained it as far as would admit of explanation.

In a similar manner, by the study of the changes which the oxygen exercises upon fousel oil from potato spirit, a definite relation was discovered between this body and valerianic acid, and it was established by numbers, that one bore the same relation to the other, as alcohol to acetic acid.

CHEMICAL RELATIONS BETWEEN UREA, URIC ACID, ALLANTOIN, AND OXALIC ACID.

The urine of man contains urea, and frequently uric acid: while the urine of some animals is deficient in uric acid, and that of others in urea. The quantity of urea in the urine diminishes with the increase of uric acid; the urine of the fœtus of the cow contains allantoin, while in the urine of man, oxalic acid is scarcely ever absent. A change in certain vital processes of the organism, is accompanied by a corresponding change in the nature, quantity, and character of the combinations, which are secreted by the kidneys. It then remains for chemists to express, quantitatively, the relations in which these bodies are observed to stand to each other, and to the processes in the organism.

THE METHOD PURSUED BY CHEMISTRY TO EXPRESS THESE RELATIONS.

Chemistry first tests, by analysis, the quantitative signification of the terms urea, uric acid, allantoin, and oxalic acid; by this, however no reciprocal relation is established between them, and it is only by an investigation into the changes which the combinations of those bodies, that have a share in the formation or change in the organism, suffer under the influence of oxygen and water, that a definite and undeniable connection can be numerically established. By the addition of oxygen to uric acid, three products are separated, viz; allantoin, urea, and oxalic acid. By a greater addition of oxygen, uric acid passes into urea and carbonic acid. Allantoin appears as an urate of urea. The comparison of the relations discovered by chemists, in the transition of uric acid into urea, with those which accompany the same process in the organism, has led to the conclusion that the requirements (in this case being an addition of oxygen) are in both cases either similar, or they deviate from each other. And these deviations furnish a new starting point for investigations, which lead to the explanation of the process.

Urea and uric acid are products of the changes which the nitrogenous constituents of the blood suffer, under the influence of water and oxygen. The nitrogenous constituents of the blood are, in their composition, identical with the nitrogenous constituents of nutrition. The relations of the latter to uric acid, and to urea and the oxygen of the air and the elements of water are expressed in Chemistry by formulæ, which explain them as far as they can be applied.

WHAT IS MEANT BY CHEMICAL FORMULAE.

It must be evident, even to the unlearned, that the difference in the properties of two bodies, is either dependent upon a different arrangement of the elements of which they consist, or upon a quantitative variety in their composition. Chemical formulæ are expressions of the different methods of arangement, the *quantitative* differences which attend the *qualitative*. Chemistry, even at the present day, cannot by the most careful analysis establish with certainty the composition of an organic body, if its quantitative relation cannot be gained from a second, which has already been ascertained without any doubt; without such aid the formulæ for the oil of bitter almonds and fousel oil could not have been obtained, and if the relation of dependence between two bodies cannot be ascertained by direct observation, the chemist is obliged to find it by his analytic art; this he does by separating the body into two or more products, investigating those which he obtains from the action of oxygen, chlorine, alkalies, or acids; and by the aid of these he succeeds finally in obtaining one or more products, the composition of which he is acquainted with, and whose formulæ he consequently knows. To the formulæ for these products, he joins that of the body which he has analysed. The sum of the whole is thus obtained by aid of the knowledge of one, several, or all the parts of which the aggregate consists. Thus if the number of equivalents of the carbon, hydrogen, and oxygen, which appertain to a molecule of sugar, are not definable by analysis; and if the skill of the chemist affords no guarantee for the correctness of his analysis of salicine or amygdaline; the analysis may be tested by the fact, that sugar combines with oxide of lead; and resolving itself into carbonic acid and alcohol by fermentation offers two combinations, the formulæ of which are known; amygdaline resolves itself into prussic acid, oil of bitter almonds, and sugar. Salicine into sugar and saligenine.

IMPORTANCE OF FORMULAE.

It is clear that when the weight of a body, and that of one or two, or all the products resulting therefrom be known, we may determine the number and relation, of one, or two, or all its elements,—that is to say, we can obtain their formulæ; and thus the result of the analysis can be verified and corroborated.

REASONS FOR THE CHEMIST TO STUDY THE PRODUCTS OF DECOMPOSITION OF A BODY.

The importance of formulæ to chemistry is clear when considered from the following point of view. A correct formula expresses the quantitative relations in which one body stands to one, two, or more bodies.

The formula for sugar expresses the whole sum of those of its elements, which combine with an equivalent of oxide of lead, and it shows the quantity of carbonic acid and alcohol, into which it resolves itself by fermentation. This will lead us to understand why chemists are often compelled to divide into numerous products the matter, whose composition they wish to establish, and wherefore they study combinations. These are all checks upon their analyses. No formula deserves implicit confidence, if the body whose composition is to be expressed have not been subjected to this operation.

MISUSE OF FORMULAE.

While some modern physiologists forgot that the knowledge of the relations of two phenomena must precede their expression in numbers, the formulæ of chemists degenerated in their hands into senseles forms of jugglery. Instead of the expression of a genuine relation of dependence, they sought to establish by numbers, relations which either did not exist in nature, or never had been observed. This property, however, does not appertain to numbers.*

HOPES.

The time will come, although perhaps the present generation will barely live to see it, when a numerical expression for chemical formulæ shall have been obtained for the measurement of all the normal energies of the organism, and of the deviations in the functions of individual parts by means of the corresponding deviations in the composition of the matter of which these parts consist, or of the products to which they give rise. We shall thus obtain a better means of quantitatively considering the effects which are induced by causes of disease, or by remedial agents, and of more clearly and accurately observing the conditions of vital phenomena. Then, indeed, it will be deemed impossible that there ever was a time, when the share taken by chemistry in the acquirement of this knowledge could be disputed, and when a doubt could be entertained concerning the way and means by which this assistance has been afforded.

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* "Microscopic anatomy shows that in the composition of the brain and spinal cord, there is a mixture of grey and white matter, and that albumen and oil occur together in these organs. Instead of availing themselves of this anatomical fact, chemists have analysed the fact as a whole; that is to say, they have investigated an unknown mixture of albumen and fat. By this means they have obtained a peculiar, apparently nitrogenous fatty acid, to which the term *cerebric acid* has been applied, and have sought to establish, on theoretical grounds, the anomaly of a nitrogenous fat.

But by a simple chemical deduction, based on Mulder's formula for protein, it is easy to show that we only obtain that which might be naturally expected, namely an evidence that cerebric acid is a mixture of albumen, fat, and phosphorus.

$$\begin{array}{lcl}
\text{For 1 at. cerebric acid} & = & P\ C_{178}\ H_{170}\ N_{2\cdot5}\ O_{38\cdot36} \\
 & \text{and} & \\
\tfrac{1}{2}\text{ at. protein} & = & C_{20}\ H_{15\cdot5}\ N_{2\cdot5}\ O_{6} \\
\text{14·36 at. fat} & = & C_{158}\ H_{136\cdot5}\ O_{14\cdot36} \\
\text{18 at water} & = & H_{18}\ O_{18} \\
\text{1 at. phosphorus} & = & P \\
\hline
 & & P\ C_{178}\ H_{170}\ N_{2\cdot5}\ O_{38\cdot36}
\end{array}$$

Hence this apparent anomaly in reference to the composition of the brain disappears."—Valentin's Lehrbuch, Vol. I. p. 174.

THE END.

End of
Volume

End of
Title